

CUTTING COMPOUNDS AND DISTRIBUTING SYSTEMS

A TREATISE ON THE KINDS OF OILS AND COMPOUNDS
USED ON DIFFERENT CLASSES OF METAL-CUTTING
TOOLS AND MACHINES, INCLUDING DISTRIBUTING AND
RECLAIMING SYSTEMS, FILTERING, STERILIZING AND
TESTING METHODS

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PREFACE

A STUDY of current practice in the lubrication of metal-cutting tools shows that in many factories where the most modern methods of manufacturing are employed, little is known concerning approved methods of cooling metal-cutting tools by means of oils and compounds. This is doubtless due to the fact that it is difficult to place this subject upon a scientific basis, owing to the numerous variable factors involved. It must not be inferred from this statement that the general practice in the use of coolants is such as to produce inefficient results, although this is doubtless true in many cases; but a great many manufacturers have been content simply to use different oil mixtures and compounds which seem to meet the requirements, instead of determining definitely that the results secured are the best obtainable, as regards either cost or efficiency.

The supplying of oils or compounds to the cutting tools of machines of different types and to plants differing in size and arrangement, requires a careful study of local conditions because different shops have different problems. The object of this treatise is to present definite useful information concerning the characteristics and uses of oils and compounds for various metal-cutting operations, specifications for the purchase of oils and compounds, methods of distributing, means for applying to the tools and work, methods of collecting after use, recovering oil from chips, filtering and sterilizing, and many other phases of this important subject.

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CUTTING COMPOUNDS AND DISTRIBUTING SYSTEMS

CHAPTER I

FUNCTIONS OF OILS AND COMPOUNDS AND THEIR GENERAL CLASSIFICATION

OIL or cutting compound is delivered to a metal-cutting tool in order to increase production, to give longer life to the tool, and in some cases to secure a better finish on the work. The functions of an oil or cutting compound may be presented under five heads: (1) To cool the work and cutter. (2) To wash away chips. (3) To lubricate the bearing formed between the chip and lip of the cutting tool. (4) To enable the cutting tool to produce a good finish. (5) To protect the finished product from rust and corrosion. Each of these functions is quite broad and prevents trouble from a large number of causes.

Cooling Tool and Work. The cooling action is the most important function. During the performance of any machining operation generation of heat is due to friction between the tool and work, and to distortion of the chips. This results in raising the temperature of both the cutting tool and the work; and if provision is not made for the removal of this heat, the temperature may become so excessive that the cutting edge of the tool breaks down. This means that there will be a great deal of time lost in stopping machines to change tools and in redressing and regrinding the worn-out tools. Another important consideration is the possibility of having the work raised in temperature so that it expands considerably during the machining operation, and while the tools may continue to

produce parts of the required size when measured at this high temperature, the work will contract on cooling so that it will be under size. It is evident, then, that manufacturers should pay careful attention to the selection of suitable cutting oils and compounds for use in cooling their cutting tools. (The term "lubricant" is commonly applied to a fluid used on metal-cutting tools, but as the cooling action of this fluid is by far its most important function, the term "coolant" is more strictly accurate.)

Washing Away Chips. In deep-hole drilling, milling and certain other machining operations, ability of the oil or cutting compound to wash away chips is a matter of great importance. For drilling deep holes the tool is ground in such a way that the chips are broken up into short pieces and the fluid is delivered in sufficient volume and under a high enough pressure so that the chips are washed out of the hole. Similarly, in milling and certain other operations there would be a tendency for chips to accumulate around the cutter and retard its action unless the cutting compound provided for washing them away. Unless high pressure is needed to facilitate washing away the chips, the fluid should be delivered at low pressure, as the results obtained in cooling and lubricating will then be more efficient.

Lubricating Action. The lubricating action is of little importance in machining such materials as cast iron, aluminum, high-carbon steel and some grades of brass, because the chips produced either break up into very small pieces or the material is removed in the form of a powder. As a result, there is little rubbing contact between the chip and tool lip, hence there is not much possibility for improving the operating conditions by the introduction of a lubricant. As compared with this condition, lubrication may be important when machining such materials as low-carbon steel, etc., where long chips are produced that curl back over the lip of the tool. In such cases a bearing is produced in which the frictional resistance is severe, and unless the oil or cutting compound is an efficient lubricant

as well as coolant, this friction will result in rapidly wearing out the tool.

The ultimate cause of a tool wearing out is due to dullness produced by rubbing or pressure of the chip upon the lip surface of the tool. The chief element causing this dullness—especially when the tool is running at high speed—is softening of the tool due to heat produced by friction of the chip upon the lip surface. In addition to friction between the chip and the lip of the tool, heat developed in cutting is also due to distortion of the chip after it is parted from the work. When machining large pieces, most of the heat is conducted away by the work, but sufficient heat will often be absorbed by the tool to result in its rapid destruction unless a suitable oil or compound is applied to absorb the heat developed.

Considerable diversity of opinion exists concerning the possibility of oil affording a lubricating action for the bearing between the lip of a tool and the chip. As oils are less efficient cooling mediums than cutting compounds dissolved in water, on account of their lower specific heats, it is assumed that the superiority of oil where long curly chips are produced is due to their lubricating action between chip and tool lip. The portion of the chip running over the lip of the tool acts as a lever which assists in tearing off subsequent sections of the chip. It will be evident that the pressure exerted by the tool is extremely high, in some cases amounting to as much as 100,000 pounds per square inch. Many believe that this high pressure would make it utterly impossible for an oil film to be maintained, as a pressure of approximately 1000 pounds per square inch is regarded as the maximum for journal bearings, etc., in which lubricating oil is used of about the same viscosity as that of oils used on cutting tools.

Probably the true explanation is found in the fact that the tool is kept flooded with oil which is not repelled by heat of the tool, as would be the case with water, and that the chip is continually sliding back over the tool lip. As a result, oil penetrates into the space that is produced in

tearing the chip from the work and is drawn back into the bearing. Were it not for the continuous supply of oil covering the chip and the constant tendency of the chip to draw oil back with it—an action which is facilitated by the rough surface of the chip—the excessive pressure would doubtless result in destroying the oil film; but under existing conditions it is probable that at least a partial lubrication of this bearing between chip and tool lip is effected.

Securing a Good Finish. There are certain classes of work where an equally good finish will be obtained whether the metal is cut dry or a coolant is applied to the tool, but when obtaining a good finish for the work is dependent upon the use of an oil or cutting compound, only a small film is actually required at the cutting tool. In most cases however, the fluid is also depended upon to enable a higher speed, feed and depth of cut to be employed than could be used if the work were machined dry. As a result, it is usually necessary to deliver a far greater volume of fluid to the tool and work than would actually be required so far as considerations of finish are concerned. This is due to several causes, among which may be mentioned necessity of cooling the tools and work, avoiding overheating the oil or cutting compound, and insuring the delivery of a sufficient volume so that there will not be occasional periods of dry cutting.

Protection from Rust and Corrosion. As regards protection of the finished product from rust and corrosion, it is well known that good cutting oils will prevent rusting of parts made from iron or steel, but cutting oils containing lard oil with too high a percentage of free fatty acid will cause verdigris to form on brass parts. This is a matter of importance and should receive consideration in drawing up specifications for cutting oils. Mixtures containing vegetable oils do not have this injurious action, but they are likely to give trouble through gumming the bearings of automatic machines; this is particularly marked in oil mixtures containing highly blown rape or cottonseed oil. Cutting compounds made by dissolving soluble oils in water

may give trouble by causing iron and steel products to rust, provided the solution is too weak or contains free acid; poor cutting compounds may also give trouble by gumming.

Classes of Oils and Compounds. A great variety of oils and cutting compounds are used for lubricating and cooling metal-cutting tools; these may be roughly subdivided into two general classes. The first consists of either pure lard oil, sperm oil, etc.; a mixture of lard oil with certain mineral and vegetable oils; and pure mineral oil or pure vegetable oil. Pure lard oil, a mixture of lard and mineral oil, and pure mineral oil are the most commonly used members of this class. The second class consists of the so-called cutting compounds which are water emulsions of soap, oil and other ingredients to prevent the water from causing rust or corrosion and to afford some lubricating action. Originally a saturated water solution of soda was used for this purpose, but this had little more than a cooling effect, and it has now been largely replaced by the so-called soluble oil compounds, which offer a certain degree of lubricating action in addition to their cooling effect. Most of these so-called solutions are really emulsions in which oil is suspended in the water, and to secure this effect the cutting compounds are made up somewhat as follows: Caustic soda or caustic potash is added to an animal oil in order to form soap, which is soluble in water. This soap is then mixed with mineral oil in the desired proportions and the mixture is added to the required volume of water. Made up in this way, the mineral oil is held in suspension in the water in the form of an emulsion, but if an attempt were made to mix mineral oil and water without the addition of soluble soap, the mineral oil would rise to the top, due to its lower specific gravity, and it would be impossible to obtain a uniform mixture. Uniformity of the emulsion is a point of the greatest importance in these cutting compounds, as separation of the oil and water may result in delivering pure water to the tools, thus causing damage by washing oil out of the machine bearings, and by rusting the machine and work.

For all classes of work except that in which the amount of heat generated by the cut is high, thus making the cooling action very important, there is probably no better medium for lubricating and cooling metal-cutting tools than pure lard oil. This should be of high quality, however, as poor grades of lard oil contain considerable amounts of free fatty acid, which tends to produce verdigris on brass parts, cause corrosion of other metals, and damage the bearings of machine tools. An excessive amount of free fatty acid will also result in gumming. One well-known manufacturer purchases lard oil under specifications calling for not more than 15 per cent of free fatty acid. The use of lard oil, as previously stated, is limited by its high cost, which is about seventy cents a gallon under normal market conditions. It was to find a less costly material that led to the introduction of mixtures of lard oil with petroleum oil, and later to the application of pure mineral oil and other inexpensive oils on certain classes of work where such substitutes would give satisfactory results in connection with metal-cutting operations.

Soluble oil compounds dissolved in water represent a step farther in the direction of price reduction, as these solutions can be produced at a low cost—ranging from about $1\frac{1}{2}$ to 16 cents per gallon, according to the degree of dilution—and many firms have gone into the manufacture of these compounds. Their low cost makes cutting compounds especially valuable for use in such industries as bolt and nut manufacture where competition is keen and where the cost of production must be kept as low as possible. Also for milling, drilling and many other machining operations the soluble compounds give entirely satisfactory results, and their low cost is a strong point in their favor. Attention is called to the fact that to give satisfactory results these compounds must be carefully made from high-grade materials. Otherwise they are likely to give trouble by rusting the work, washing oil out of machine bearings, and gumming slides and other moving parts.

Each manufacturer has his own special formulas for use in making these compounds, but the following is a typical

mixture: Caustic soda, 0.65 per cent; alcohol and water, 5.80 per cent; resin acid, 1.64 per cent; fatty acids, 11.76 per cent; mineral oil of 22.5 Baume specific gravity, 80.15 per cent. This mixture is dissolved in water, the degree of dilution being dependent on the nature of the machining operation and the kind of metal being machined.

Compounds Containing Deflocculated Graphite. In 1906, Edward G. Acheson was experimenting with methods of treating carborundum in the electric furnace, and during the course of this work he discovered a small amount of very soft unctuous graphite, which he immediately recognized as an ideal cooling medium for metal-cutting tools. Commercial methods of making this graphite were developed and patented.

Having developed a method of producing this graphite Mr. Acheson undertook the problem of working out details for its application as a cutting compound. His early efforts consisted in using the graphite dry or mixed with grease, the mixture being marketed under the copyrighted name "Gredag." In an effort to extend the field of usefulness of this graphite, experiments were conducted with the view of using the graphite in suspension in different grades of oil, but trouble was encountered by the graphite settling out. In the latter part of 1906, it was found possible to obtain a stable mixture of graphite held in suspension in water, by adding a small quantity of gallotannic acid. This treatment was defined as "deflocculation" and the graphite was called "deflocculated" graphite. The liquid is black and passes easily through the finest filter paper. This mixture of water and graphite was given the name "Aquadag." A valuable property of "Aquadag" is the fact that it does not have any tendency to rust the tools or work. In 1907, Mr. Acheson succeeded in transferring deflocculated graphite from the water medium to an oil medium in which it also remained permanently suspended, and this cutting compound was given the "Oildag." Both these cutting compounds are made by the Acheson Graphite Co., Niagara Falls, N. Y.

Results Obtained with Compounds Containing Graphite.

An idea of the efficiency of "Aquadag" and other compounds containing deflocculated graphite may be gathered from the experience of a certain machinery manufacturer. The records showed that the cutting-off tool of a lathe engaged in cutting off cold-rolled steel rods about one inch in diameter required sharpening about every sixty cuts when an ordinary soap cutting compound was used. When "Aquadag" was used, the life of the tool was increased to 980 cuts, and the finish was smoother.

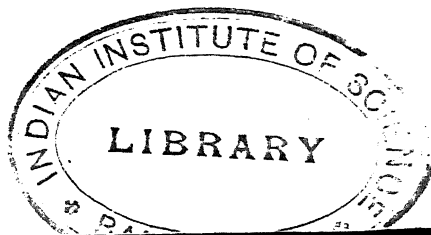
Since its discovery, "Aquadag" has been used for many other machining operations and has given very satisfactory results. For instance, in reaming holes in bronze bushings it was found that an ordinary cutting compound resulted in producing a hole about 0.0002 inch under size, due to the expansion caused by the heat generated by the cut; but when "Aquadag" is used, friction and the generation of heat may be so far reduced that there is practically no expansion, and as a result the hole is practically the full size of the reamer. That power consumption is reduced through the use of this cutting compound is demonstrated by the fact that in one factory it was necessary to run a machine on back-gear when using an ordinary cooling compound, but when "Aquadag" was used, it was possible to operate the machine on open belt, thus securing the double advantage of a reduction of power and an increase of speed. This cutting compound has been used for boring, cutting off, milling, thread cutting and other operations, and has given uniformly satisfactory results. However, the workmen are prejudiced against its use in spite of the efficient results obtained, as it makes them so dirty.

Oils Used as Tool Lubricants and Coolants. A great variety of oils are used on metal-cutting tools. The selection of a suitable oil will depend upon the class of machining operation and the kind of metal being machined, according to the principles explained. Some oils are used pure, notable examples being lard and petroleum oil; in other cases it is desirable to use a mixture of oils in order to

obtain the required consistency and a lower cost than pure lard oil, etc.; still another application is in the compounding of so-called soluble oil mixtures that are diluted with water to form the cutting emulsions.

There are three chief classes of oils, namely, animal oils, vegetable oils, and mineral oils. As their name implies, animal oils are extracted from the fatty tissues of certain animals and fish; vegetable oils are obtained from the fruits or seeds of numerous plants. Both of these are known as "fixed" oils, because they cannot be vaporized or distilled when heated without undergoing chemical decomposition. This distinguishes such oils from the "volatile" oils, which may be readily distilled by the application of heat without being decomposed. These are known as mineral oils because they are obtained from petroleum or rock oil. Certain vegetable oils when exposed to the air absorb oxygen rapidly, forming an elastic varnish-like film, and on this account they are known as "drying" oils, of which linseed oil is the best known example. Other vegetable oils show no tendency to form such films and are known as "non-drying" oils. There is a third class, called "semi-drying" oils, which comes between the two preceding classes. Either non-drying or semi-drying oils may be used for coolants. All fixed oils contain a certain amount of fatty acids, and if allowed to stand in the air this increases and the oil becomes rancid. It is not within the province of this treatise to enter into a discussion of the chemistry of oils, but it will be of interest to explain briefly the methods used in obtaining the more important classes of oils used for lubricating and cooling cutting tools.

Cottonseed Oil. This oil gives good results when used pure for lubricating taps and threading tools, etc. It is also used as a constituent of some mixed oils and cutting compounds. As its name indicates, cottonseed oil is obtained from the seeds of cotton plants, extraction being effected by the application of pressure. The presence of dark brown cell materials in the kernel imparts a deep red color to the oil as it runs from the press, this color depend-



ing largely upon the freshness of the seeds. The crude oil is refined by treating it with a weak solution of caustic soda, which reduces the color to a pale yellow or light brown. The best grade is known as "prime summer yellow" and should be free from water and possess a sweet flavor and odor. A second grade, known as "summer oil" will become cloudy and partly freeze at a comparatively high temperature, a fatty material separating out, which is known as stearine. By suitable treatment, cottonseed oil may be made to remain perfectly clear at 32 degrees F. for a considerable length of time; oils of this grade are known as "winter oils"—either "prime winter white" or "prime winter yellow." Cottonseed oil comes in the "semi-drying" class.

Fish Oils. These oils are more extensively used in the heat-treatment of steel than in cooling. As implied by its name, menhaden oil is obtained from menhaden, which are somewhat larger than herrings. In extracting the oil, the fish are placed in boiling pans and treated with steam which digests the flesh in such a way that after standing for some time oil rises to the top of the water and is skimmed off. The color of this oil depends upon the freshness of the fish from which it is extracted and upon the length of time the boiling process is continued. The darker grades of oil are obtained when the boiling process is conducted for too long a time or when the fish is putrid. The crude oils vary in color from yellow to brown, but are bleached in the process of refining to almost a pure white. Unfortunately, various grades of fish oil are often substituted for menhaden oil. These are extracted from many kinds of fish by a method similar to that described. All fish oils are characterized by their distinctive odor, which is likely to be very rank in the case of dark colored oils.

Lard Oil. Lard oil has been applied very extensively to metal-cutting tools, and is either used pure or as a constituent of oil mixtures or cutting compounds. The best grade of lard oil is extracted from layers of fat, known as "leaves," taken from the loins of the hog. This fat is placed

in cloth bags and subjected to hydraulic pressure which squeezes out the oil. Other grades of lard oil are obtained by boiling in water the fats and tissues surrounding the abdomen. The lard is skimmed from the surface and kept warm for several hours to allow the tallow to crystallize, this process being known as "seeding." The seeded lard is then put into cloth strainers and subjected to hydraulic pressure, which produces the lard oil of commerce. Lard oil may be of the following grades: "Prime winter strained," "prime," "off prime," "extra No. 1," "No. 1," and "No. 2," depending upon the class of material from which it is extracted. Judged from the standpoint of users of lard oil, the chief difference between these lies in the percentage of fatty acid, which may run as high as 30 per cent in the case of a very poor grade of oil. This is a severe detriment on account of the corrosive action exerted by this acid on the work—notably in the case of brass products—and on the bearings of machine tools. To give satisfactory results lard oil should not contain over 15 per cent of fatty acid. Depending upon the temperature and pressure employed in its preparation, the "cold test" or temperature of solidification varies greatly, so that some grades of lard oil will deposit a fatty material, known as stearine, at ordinary room temperature and become stiff at 50 degrees F. High grades of lard oil will remain clear at much lower temperatures. The colors of lard oil range from practically water white to a deep brown, oils of darker color being the inferior grades.

Neatsfoot Oil. Neatsfoot oil is recommended for use on broaches—especially when working on very hard material. Neatsfoot oil is generally understood to be obtained from the feet of cattle, but the commercial oil sold under this name is also extracted from the feet of sheep, hogs, horses, and other animals. Extraction is carried on in the following way: The feet are scalded with boiling water to loosen the hoofs, which are then pulled out and the feet are boiled for eight or ten hours. Oil rises to the surface of the water and is skimmed off from time to time, being poured through

a screen to separate as much as possible of the suspended matter, after which the oil is dried with steam pipes and filtered. The purpose of removing the hoofs from the feet is to prevent darkening the color of the oil. If proper care is taken in its preparation, neatsfoot oil is low in fatty acid—generally less than $\frac{1}{2}$ per cent—but commercial oil of poor grade may contain as much as 25 or 30 per cent. Neatsfoot oil is of a yellow color and it flows freely.

Olive Oil. Some people recommend olive oil as a substitute for lard oil for lubricating cutting tools. It is said to flow more freely and give less trouble through becoming thick in cold weather. Olive oil costs more than lard oil, but it is said to be highly efficient and the amount of oil carried away by chips is less than is the case with lard oil. This oil is extracted from olives and is sold in many different grades, the best of which—known as “edible oil”—is obtained from hand-picked olives. These are crushed in a mill without breaking the seeds, and after separating the fruit from the seeds the oil is extracted in a hydraulic press. A second grade of oil is obtained by pouring cold water over the pressed fruit and subjecting it to a second pressing operation, after which the pulp is once more mixed with hot water and again pressed to yield a third grade of oil. The color of olive oil varies from pale greenish yellow to a dark olive green; as the coloring matter is extracted from the olives with the oil, the lower grades have the highest color. These grades are inferior, because their high fatty acid content tends to give trouble from gumming and corrosion. Olive oil is a “non-drying” oil.

Petroleum Oil. Mixed with lard oil in various proportions, petroleum finds application as a constituent of the well-known “mineral” lard oil. It is also employed in the soluble oil compounds; and for such machining operations as milling and drilling it may be used pure. Crude petroleum oil is obtained in many parts of the world, notably in the states of Pennsylvania and Texas, in Mexico, and in Southern Russia. Crude oil, as it comes from the wells, carries considerable suspended mineral matter which must be removed. As previously mentioned, petroleum oil is of

the so-called "volatile oil" type, and is refined by distilling. The stills are heated at different temperatures in order to divide the oil into "fractions" of various composition, important among these are naphtha, gasoline, and kerosene, which are obtained at the lower temperatures; then come the different grades of oils and greases that are secured by the successive application of higher temperatures. The color of those grades of petroleum oil used on metal-cutting tools is dark yellow or light brown.

Rapeseed Oil. As a constituent of certain oil mixtures and cutting compounds, this oil finds a limited application in machine-shop work. It sometimes goes under the trade name of "Colza" oil and is extracted from rape seed. This is a "semi-drying" oil; the color is pale yellow and it has a high viscosity and flows slowly.

Rosin Oil. This oil is used as a constituent of certain cutting compounds. It is obtained by subjecting rosin to a process of destructive distillation. This consists of heating rosin in a retort to a temperature sufficiently high for it to be decomposed, allowing vapors to be driven off; among these are the vapors of rosin oil. This process is carried on in cast-iron stills which hold charges ranging from three to five tons. Crude rosin oil is a brown viscous liquid with a characteristic odor and noticeable luminescence of a bluish or violet tinge. When kept at a temperature of 300 degrees F. for several hours the crude oil loses about 4 per cent of its more volatile constituents and assumes a green luminescence which, however, can be removed by chemical treatment, giving a finished oil of a pale brown color. Rosin oil is a "drying" oil, and is not suitable for use as a coolant except as a constituent of certain mixtures.

Sperm Oil. Toolmakers of the old school still regard sperm oil as the best possible oil for difficult machining operations, but its scarcity and high price limit the use of this oil to relatively few shops. Sperm oil is extracted from the contents of the head cavity and several smaller receptacles throughout the body of the sperm whales. During the life of the animal the contents of these cavities are in a fluid condition, but no sooner has this "head

matter" been removed than white crystalline flakes of wax, known as spermaceti, separate out, leaving a clear yellow fluid possessing a distinctive fishy odor. This sperm oil is the lightest and most fluid of all the fixed oils. An inferior grade of sperm oil is obtained from the blubber of sperm whales. Practically all sperm oil is extracted on shipboard. The crude oil is delivered to refineries, where it is placed in tanks and chilled to 32 degrees F. and allowed to stand for a couple of weeks to freeze out the spermaceti. The semi-solid mass is placed in cloth bags and subjected to hydraulic pressure which squeezes out the oil known as "winter sperm." The material left in the bags is warmed to 50 degrees F. and again pressed to obtain "spring sperm oil." A third quality of oil, known as "taut pressed sperm oil," is obtained by further pressing at higher temperature. Refined sperm oil is of a pale yellow color and has only a faint odor. Certain grades of fish oil and whale oil are often sold for sperm oil.

Tallow and Tallow Oil. These materials are sometimes used in making cutting compounds. Tallow is the general name applied to the fat of certain animals; an adjective preceding it indicates the source, as beef tallow is obtained from cattle, mutton tallow is obtained from sheep and goats, etc. The process of melting out the fat from the tissue and membrane is generally carried on in large kettles heated by live steam. At temperatures from 60 to 80 degrees F., tallow is a mixture of solid and fluid fats, and if subjected to pressure the fluid can be separated, tallow oil being the name applied to this liquid. Beef and mutton tallow are similar in general characteristics, and as regards their application for commercial purposes the term "tallow" may indicate either one. Tallow is white and the color of tallow oil is pale yellow.

Whale Oil. As applied to metal-cutting tools, whale oil finds application in making compounds and as a constituent of mixed oils. The best grade of whale oil, known as "train" oil, is extracted from the blubber of Arctic or Greenland whales, but the whale oil of commerce is obtained from many species of whales. Some whale oil is extracted

on shipboard, and the crude oil is delivered to refineries on the coasts. The blubber of a large whale will sometimes yield as much as 7500 gallons of oil, while a small whale will yield only from 50 to 100 gallons. The best grades of whale oil are obtained from the first boiling, after which the blubber is subjected to a second treatment, which yields a slightly inferior oil. These are known as No. 0 and No. 1, respectively. A third grade of oil is extracted from the residual blubber and flesh of the whale. Even the best grades of this oil have marked drying properties, making them unsuitable for use in the original condition. The

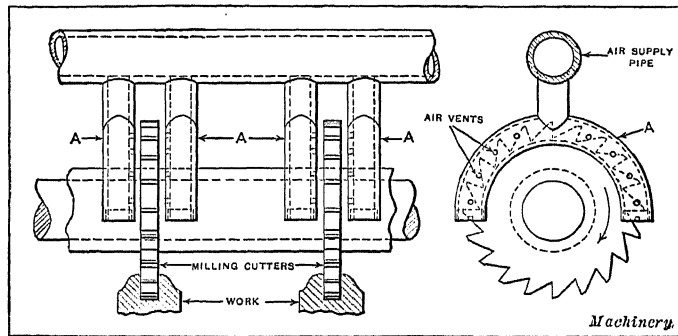


Fig. 1. Cooling Milling Cutters with Compressed Air which flows through Perforated Pipes and Impinges upon the Cutter Teeth

color varies from white to yellow, according to grade, and is a fairly reliable indication of quality.

Use of Compressed Air as a Coolant. In milling cast iron and similar operations where short chips are produced, satisfactory results may often be obtained by the use of compressed air delivered to the tool and work in such a way that it absorbs the heat generated by the cut. An advantage of the use of compressed air is that there is absolutely no tendency to gum, and the work is clean and dry when it leaves the machines; also, absence of moisture does away with all danger of rusting the work or machine parts. Fig. 1 shows the method of applying compressed air in milling a typewriter part in the plant of the Royal Typewriter Co., Hartford, Conn. This bar has a slot $7/32$

inch wide by 13.32 inch deep milled for its entire length, which is $8\frac{3}{4}$ inches. The compressed air is delivered through an air line arranged in such a way as to decrease the pressure at the machine to one pound per square inch. At each side of the milling cutters there are pipes A bent to the same radius as the cutters; a number of holes are drilled in these pipes, so that air impinges directly upon the milling-cutter teeth. The pressure of the air is not sufficient to cause the chips to be blown around, but the air absorbs heat from the cutters and work, preventing overheating and excessive wear. The slot is finished at a single cut by milling cutters $2\frac{3}{4}$ inches in diameter which run at 120 revolutions per minute. One piece is finished in one minute, twelve seconds. When finished, the work is sufficiently cool so that it can be picked up and held in the hand.

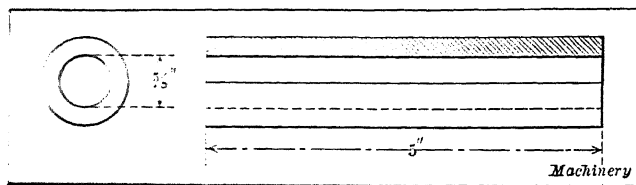


Fig. 2. Machine-steel Piston-pin drilled with Compressed Air as Coolant

Fig. 2 shows another example of the application of compressed air for cooling cutting tools. In this case the operation is performed on a Cleveland automatic. The work is a 0.20 to 0.30 per cent carbon machine-steel piston-pin; this is of particular interest because although it is known that compressed air can be used in drilling cast iron with satisfactory results, few mechanics would expect to be able to use it in deep-hole drilling operations in machine steel. The automatic screw machine is fitted up with the regular oil-feed mechanism for the turret tools, but instead of forcing the oil through the piping, compressed air is delivered at a pressure of 75 pounds per square inch. The drill is a regular high-speed steel oil-tube type, with cutting edges ground to break up the chips so that they may be readily removed. So efficient is the compressed air that it

is found unnecessary to withdraw the tool until the piece has been completely drilled to a depth of 5 inches, using a feed of 0.015 inch per revolution and a surface speed of 70 feet per minute. This speed is lower than a high-speed steel drill will stand, but it has been found that a heavy feed with a lower speed gives the best results, as it produces chips which may be easily blown out. The chips are quite cool when they leave the hole and an excellent finish is produced. Before adopting compressed air, lard oil was used for this job, but this proved unsatisfactory due to heating and binding of the drill before the coolant had reached the bottom of the hole. Apparently the oil made the chips adhere to one another and prevented them from being washed out freely, while with the air the chips are kept clean and cool and are blown out as rapidly as they are produced.

Factors Influencing Selection of Oils and Cutting Compounds. It has been stated that so many variable conditions enter into the cooling and lubricating of cutting tools that it is difficult to secure exact information concerning the action of an oil or compound on the tools. Certain general facts have been established, however, and these form the basis which governs the selection of a suitable coolant to use in different cases. One of these is the condition under which the machine is operated. A low speed and shallow cut means that little lubricating action is necessary, while a low speed and heavy cut—especially in cases where the material is tough—means that the fluid must possess great lubricating power, hence the use of oil is advisable. Operating at high speed and taking a shallow cut calls for a fluid possessing superior cooling properties, and for this work cutting emulsions are used, due to their high capacity for absorbing heat; if even a low viscosity cutting oil were employed, the friction and heat developed would cause excessive heating of the tools and finished work with troubles from this cause to which reference has already been made. Operating under high speed and heavy cut calls for a fluid with both cooling and lubricating proper-

ties. For this purpose a heavily compounded cutting emulsion should be used, because the water solution most effectively dissipates the heat, and by heavily compounding the solution a fairly effective lubricating action is obtained.

The effect of the kind of chips produced in cutting different classes of metals upon the requirements of an oil or cutting compound has been briefly referred to, and in addition it may be mentioned that the selection will be governed to some extent by the hardness of the metal. The selection will also be affected by the character of the machine, as well as the conditions of speed and the depth of cut under which it is operated.

Purchase of Cutting Oils and Compounds. There are many machine shops using oils and compounds on metal-cutting tools that do not have adequate facilities for testing to determine the purity of cutting compounds and their suitability for handling the work for which they are intended. The best course for proprietors of such shops to follow is to deal with manufacturers of oils and cutting compounds of known reputation. Many different mixtures of oils and numerous cutting compounds appear identical, so that there is always a temptation for a buyer to favor the one that he can secure at the most advantageous price. But the experience of machine shop managers confirms the soundness of making a practice of purchasing a high-grade oil or compound produced in a factory with facilities for testing raw materials and mixing them in such a way as to insure their meeting the purchaser's requirements. Also, such factories have an established reputation that is a particularly valuable business asset in the sale of oils and cutting compounds, and one that they will not be likely to risk losing for the sake of making unfair profits. Complaints are frequently made of unsatisfactory results obtained from mixed oils and cutting compounds sold ready for use. If these were carefully investigated, it would often be found that the trouble was due to one of two causes: Either the customer was buying an oil or compound unsuited for his work, or he was making his purchase from

an unreliable firm that was selling him an inferior substitute instead of that for which he was paying

Purchase of Oils and Cutting Compounds Under Specification. When the quantity of oil or cutting compound used is large enough so that expenditures for this item run into considerable sums during the year, it is good practice to have definite specifications under which purchases are made. The Navy Department has drawn up specifications for the purchase of oils, soluble oils, and cutting compounds sold in the form of paste. Although these are more complete than those required by the average manufacturer, they are given in order to show the requirements for each of these materials.

NAVY DEPARTMENT SPECIFICATIONS

Oil, Lard, Mineral

Purpose. To be used for machine cutting-tool lubricant, either unadulterated or compounded with mineral oil or soda and water.

Composition. To be clean and homogeneous; free from disagreeable odors, rancidness, sediment, or ingredients injurious to persons handling the material; and to be easily soluble and retain oily consistency in kerosene or soda and cold-water mixtures. To have a specific gravity at 15 degrees C. of about 0.90, a flash point in an open tester of not less than 180 degrees C., and flow at 4 degrees C. To contain not less than 25 per cent and not more than 35 per cent fixed saponifiable oils, from 60 to 70 per cent mineral, and not more than 5 per cent free fatty acid (calculated as oleic acid).

Viscosity. Measured in a Saybolt viscosimeter (with thirty seconds water rate at 15 degrees C.) the oil to show about 185 seconds at 38 degrees C. and 115 seconds at 48 degrees C.

Gumming. A saucer with enough test oil to cover the bottom when placed in an oven at a constant temperature of 120 degrees C. for a period of eight hours, when taken out and permitted to cool gradually, shall show no signs of a gummy residue.

Corrosin. Strips of polished steel to show no appreciable corrosion in two weeks' time when partly immersed in samples of the oil, or in a mixture of the oil and kerosene, or in an emulsion of the oil, soda, and water.

Physical Test. Three gallons of the oil unadulterated will be put into a steel tank and pumped at the rate of one gallon per minute over a steel cylinder heated by an electric coil consuming 440 watts which maintains a constant temperature at 100-degrees C. in air. After a period of three hours the maximum rise of temperature of the oil shall not exceed 30 degrees C.

Soluble Cutting Oils or Cutting Compounds (Liquid Form)

Purpose. To be used in emulsion with water for machine cutting-tool lubricant.

Composition. To be a clean and homogeneous mixture of soluble alkali soap in mineral and fixed saponifiable oils. It shall be free from disagreeable odors, sediment, mineral acids, ingredients injurious to persons handling, and shall contain not more than 10 per cent water and not more than 20 per cent soluble alkali soap.

Emulsification. To be capable of readily mixing with water in all proportions without the use of sodium carbonate or other addition to form a stable emulsion.

Lubrication. The emulsified oil must lubricate turret and automatic machines sufficiently to prevent sticking, and must show no tendency to leave a gummy residue.

Corrosin. Strips of polished steel are to show no appreciable corrosion after immersion in the emulsion for two weeks.

Physical or Cooling Efficiency Test. When three pints of oil are put into emulsification with three gallons of water and permitted to flow at the rate of one gallon per minute over a steel cylinder heated by an electric coil consuming 440 watts designed to maintain a constant temperature of 100 degrees C. in air for a period of eight hours, the maximum rise of temperature of the emulsion shall not exceed 12 degrees C.

Cutting Compound (Paste Form)

Purpose. To be used for machine cutting-tool lubricant when mixed as directed.

Composition. To contain not more than 50 per cent water, not more than 25 per cent mineral oil and between 20 and 30 per cent alkali soap, and the remainder fixed saponified oils. To be free from disagreeable odors, rancidness, or ingredients injurious to handling; and to be easily soluble in water, forming a suitable stable lubricating emulsion which shows no tendency to leave a gummy residue and which will not appreciably corrode strips of polished steel in two weeks' time.

Physical Tests. When prepared in an emulsion such as recommended by the manufacturer, and which shall contain not more than 16 pounds of compound and not less than 24 gallons of cold water, it shall lubricate the tool so that in making 1-inch bolts 6 inches long turned to a finished size in one cut from $1\frac{5}{8}$ -inch hexagonal bar of nickel steel with three inches of chased thread on a turret monitor, with a travel of turret carriage, 6 inches in six seconds and flow of compound, 5 pounds per minute, the following conditions will obtain: The temperature rise of the stock shall not be greater than 35 degrees F., and the standard steel turning or parting tool not to require additional grinding until test is finished on ten bolts. The temperature during this test shall be measured by placing a chemical thermometer on the finished stock within one-half inch of the tool. The standard steel turning and cutting tool mentioned is of tungsten tool steel, class No. 2, in accordance with Navy Department specifications for "tool steel." The hexagonal nickel-steel bars will be in accordance with Navy Department specifications for "hot-rolled or forged nickel steel."

CHAPTER II

OILS AND COMPOUNDS FOR DIFFERENT MACHINING OPERATIONS

THE diversity of practice which exists in the use of oils and compounds on metal-cutting tools is largely due to numerous variable factors entering into the action of an oil or cutting compound which make it difficult to determine exactly the nature of the service performed by the fluid. When one manufacturer is using a soluble cutting compound costing, say, two cents a gallon, and another manufacturer uses petroleum oil costing twenty-four cents a gallon for the same purpose, it would appear that the latter practice involves unnecessary expense, and possibly this is the case. But the difference may not be so marked as a mere comparison of costs makes it appear, owing to the fact that the oil may wear longer and may enable the cutting tools to be operated for a greater length of time before they require grinding; or the work may be improved in quality and the wear of machine-tool equipment decreased.

Mineral Lard Oil Mixtures. A careful investigation of practice in representative American manufacturing plants goes to show that there are particular classes of work in which each of the commonly used coolants gives exceptionally good service. Pure lard oil is very effective, but owing to its high price, the use of lard oil undiluted is not generally recommended except for such machining operations as tapping, reaming, and similar classes of work where a high finish and great accuracy are required.

For automatic screw machine work some manufacturers use pure lard oil, but here the need of a large volume of oil causes the question of economy to play an important

part; as the so-called "mineral lard oil" mixtures, ranging from 30 per cent of lard oil and 70 per cent of medium petroleum oil up to equal parts of lard oil and petroleum oil, have been found to give practically as good results as pure lard oil, it seems desirable to use these mixtures. Furthermore, mineral lard oil has an advantage over pure lard oil in that it is more fluid and thus runs more freely to the tool and work; also, this mixed oil is not so likely to give trouble from gumming. Lard oil possesses a peculiar unctuous property that is not found in other oils, and it is a matter of common experience that trouble is likely to develop on automatic screw machine work—particularly in cases where forming, threading and tapping operations have to be performed—unless the coolant used contains lard oil as one of its constituents.

Mineral lard oil mixtures are used for automatic screw machine work and for numerous other machining operations, and the following mixtures have been found highly satisfactory: (1) Equal parts of lard oil and petroleum machine oil. (2) Lard oil, 30 per cent, and mineral oil, 70 per cent. (3) On Cleveland automatic screw machines for cutting steel of different grades, from 10 to 12 per cent pure lard oil and 88 to 90 per cent neutral mineral oil of about 32 degrees Be. gravity. The fluidity of this mixture permits it to reach the extreme cutting point of the tool and it possesses sufficient viscosity to form the required film on the work. (4) One part lard oil and three parts Pennsylvania petroleum oil. (5) Mineral lard oil reduced with from $33 \frac{1}{3}$ to $66 \frac{2}{3}$ per cent kerosene or paraffin. (6) Ten gallons lard oil to one gallon kerosene. (7) For drilling, reaming and gear planing, 30 per cent lard oil and 70 per cent petroleum.

With the view of reducing the cost of coolants, some manufacturers have resorted to the use of pure petroleum oil on such machining operations as milling and turning, which seems to be a step in the direction of economy that is justified, because the mineral oil is giving satisfactory service.

Soluble Oils and Compounds. A further step in reducing the cost was made through the introduction of the so-called soluble oils and compounds used with water to form the well-known white cutting emulsions which are available at prices ranging from about $1\frac{1}{2}$ to 15 cents a gallon, according to the degree of dilution. Opinion is divided in regard to the advisability of using these water emulsions, but the following seems to be representative of experience in shops where the question has received careful consideration: for milling, drilling, grinding and other operations where short chips are produced, these water emulsions give very satisfactory results. They flow freely, and as water has a higher specific heat than any of the oils, these emulsions are more efficient than oil for cooling. In cases where lubrication is of some importance, as well as cooling, it is good practice to add more of the soluble oil or paste compound in mixing the emulsion than where only cooling is necessary.

It has been a matter of fairly general experience that the soluble oil compounds are unsuitable for use on automatic screw machines, turret lathes and other machines having slides and bearings into which the emulsion can easily find its way. When fluids containing water are used on machines of this kind, the detergent action is a source of trouble because the oil is washed out of the bearings, and serious wear results.

The preceding is a brief summary of experience with the use of pure lard oil, mineral lard oil, pure mineral oil and soluble cutting compounds, which are the four classes of coolants used on the majority of the cutting tools in American factories. Detailed information is given in the following paragraphs concerning the oils and cutting compounds used for typical machining operations on different kinds of metal.

Oils and Compounds for Different Machining Operations. The following recommendations regarding oils and compounds for various machining operations on different classes of metals, conform to the practice of many repre-

sentative builders and users of different types of machine tools. Where the use of "compound" is recommended, it means any of the emulsions made by mixing soluble oil or paste with water. No recommendations are made in the case of such materials as cast iron, etc., where it is good practice to conduct the machining operation dry.

Automatic Screw Machine Work. High-carbon and alloy steel: lard oil, mineral lard oil consisting of ten parts mineral lard oil and one part kerosene. Low-carbon steel: mineral lard oil, asphaltic base petroleum oil, paraffin oil and mineral lard oil in equal proportions. Wrought iron: mineral lard oil, asphaltic base petroleum oil. Brass: mineral lard oil, light paraffin oil. Bronze: mineral lard oil, asphaltic base petroleum oil. Copper: mineral lard oil. Aluminum: mineral lard oil, compound. Hard rubber: dry, compressed air. Fiber: dry. In all cases the mineral lard oil mixture may run anywhere from equal parts of mineral oil and lard oil down to 70 per cent mineral oil and 30 per cent lard oil.

Boring. High-carbon and alloy steel: mineral lard oil, lard oil, paraffin oil. Low-carbon steel: mineral lard oil, petroleum oil, compound. Brass: compound. Bronze: compound. Copper: lard oil or kerosene. Aluminum: kerosene.

Broaching. High-carbon steel: neatsfoot oil, compound. Low-carbon steel: neatsfoot oil, compound. Wrought iron: neatsfoot oil, compound. Malleable iron: neatsfoot oil, compound. Bronze: neatsfoot oil, compound.

Cutting off with Cold-saws. High-carbon and alloy steel: mineral lard oil, mixture of two parts kerosene and one part signal oil, petroleum oil. Low-carbon steel: mineral lard oil, petroleum oil, compound, mixture of two parts kerosene and one part signal oil. Wrought iron: mineral lard oil, petroleum oil, compound. Bronze: compound.

Cutting off with Hacksaw Machines. On all metals use soda-water mixture of two pounds soda to three gallons water.

Drilling. High-carbon and alloy steel: mineral lard oil, lard oil. Low-carbon steel: mineral lard oil, petroleum oil, compound. Very hard steel: turpentine or mixture of turpentine and spirits of camphor, kerosene. Cast iron: compressed air. Wrought iron: mineral lard oil, petroleum oil, compound. Malleable iron: compound, petroleum oil. Brass: compound. Bronze: compound. Copper: lard oil, mineral lard oil, kerosene. Aluminum: kerosene, beeswax or tallow (rubbed on rotating drill after cutting two or three holes). Monel metal: compound. Glass: turpentine, turpentine and spirits of camphor, kerosene.

Forming. High-carbon and alloy steel: mineral lard oil, lard oil, paraffin oil, mixture of two parts kerosene and one part signal oil. Low-carbon steel: mineral lard oil, petroleum oil, compound, mixture of two parts kerosene and one part signal oil. Wrought iron: petroleum oil, compound. Brass: compound. Copper: lard oil or kerosene. Aluminum: kerosene.

Gear-cutting. High-carbon and alloy steel: lard oil, mineral lard oil. Low-carbon steel: mineral lard oil, petroleum oil, compound. Bronze: lard oil, mineral lard oil, compound.

Gear Hobbing. High-carbon and alloy steel: lard oil, mineral lard oil. Low-carbon steel: mineral lard oil. Cast iron: compound. Brass: compound. Bronze: mineral lard oil, compound.

Gear Planing. High-carbon and alloy steel: mineral lard oil. Low-carbon steel: mineral lard oil. Bronze: mineral lard oil.

Gear Shaping. High-carbon and alloy steel: lard oil, mineral lard oil, turpentine, kerosene. Low-carbon steel: mineral lard oil, compound, turpentine, kerosene (on steel where trouble is experienced from tearing the metal, add a small amount of powdered sulphur to the lard oil or mineral lard oil). Cast iron: compound. Brass and bronze: compound.

Grinding. High-carbon and alloy steel: compound. Low-carbon steel: compound. Cast iron: compound. Wrought iron: compound. Brass: compound. Bronze: compound.

Milling. High-carbon and alloy steel: mineral lard oil, compound, petroleum oil, paraffin oil, lard oil. Low-carbon steel: compound, mineral lard oil, petroleum oil. Cast iron: compressed air. Wrought iron: mineral lard oil, compound, petroleum oil, soda water. Brass: compound. Bronze: compound, kerosene. Copper: mineral lard oil, lard oil, kerosene. Aluminum: kerosene.

Reaming. High-carbon and alloy steel: lard oil, mineral lard oil, sperm oil, mixture of lard oil and white lead of about consistency of glue. Low-carbon steel: lard oil, mineral lard oil, compound, lard oil and white lead. Wrought iron: lard oil, mineral lard oil. Brass: compound. Copper: mineral lard oil, lard oil, kerosene. Aluminum: lard oil, kerosene.

Tapping. High-carbon and alloy steel: lard oil, mineral lard oil, mixture of 90 per cent tallow and 10 per cent graphite, cottonseed oil. Low-carbon steel: lard oil, mineral lard oil, tallow and graphite, lard oil and white lead mixed to consistency of glue, cottonseed oil. Cast iron: lard oil, compound, white lead. Wrought iron: lard oil, compound. Malleable iron: lard oil, compound. Brass: lard oil, lard oil and white lead mixed to consistency of glue. Copper: lard oil. Aluminum: lard oil, kerosene, beeswax or tallow (rubbed on rotating tap after each operation). Babbitt: lard oil, soap (packed into hole before tapping). Nuts: mineral lard oil, compound.

Thread Cutting. High-carbon and alloy steel: lard oil, mineral lard oil, cottonseed oil, grapeseed oil. Low-carbon steel: mineral lard oil, mixture of mineral lard oil and 25 to 50 per cent kerosene, turpentine and white lead, lard oil, cottonseed oil, grapeseed oil. Very hard steel: turpentine. Wrought iron: mineral lard oil, compound. Brass: compound. Bronze: mineral lard oil. Copper: mineral lard oil. Aluminum: kerosene. Monel metal: mixture of lard oil and white lead reduced to consistency of glue.

Thread Milling. High-carbon and alloy steel: mineral lard oil, paraffin oil. Low-carbon steel: mineral lard oil, paraffin oil of 28 degrees Be. gravity.

Threading with Dies. High-carbon and alloy steel: lard oil, sperm oil. Low-carbon steel: lard oil, mineral lard oil, compound. Wrought iron: lard oil, mineral lard oil. Brass: mineral lard oil, compound. Copper: lard oil, mineral lard oil.

Turning. High-carbon and alloy steel: mineral lard oil, lard oil, compound, paraffin oil of 28 degrees Be. gravity, signal oil. Low-carbon steel: mineral lard oil, signal oil, petroleum oil, compound. Wrought iron: petroleum oil, compound. Brass: compound. Bronze: compound. Copper: lard oil or kerosene. Aluminum: kerosene. Monel metal: compound. Hard rubber: cold water.

Importance of Complete Stability of Cutting Emulsions. When cutting emulsions are made by mixing paste or soluble oil with water it is important for the oil or paste to be uniformly mixed in the water and for the emulsion to be stable at all temperatures under which it is likely to be used. When this is not the case, there is danger of certain constituents of the oil settling out in layers, resulting in lack of uniformity of the emulsion, which will prevent it from having the maximum effect, and may cause rusting of machines and product. The user of cutting compounds will do well to place in tall glass bottles test samples mixed with water in the proportions recommended for the class of work on which the emulsion is to be applied and observe whether there is any tendency for the constituents to settle out. Any compounds which show this tendency should not be used.

Mixing Cutting Oils and Emulsions. In order to secure the best results with oil mixtures or cutting emulsions which the consumer mixes in his own shop, great care should be taken to follow the instructions given by the firm from which oils are purchased, as even slight deviations from the recommended practice will often seriously reduce the efficiency in cooling or lubricating. It is good practice to standardize cutting compounds as far as possible, and in every case a competent person should have charge of their handling and mixing. Satisfactory results cannot be

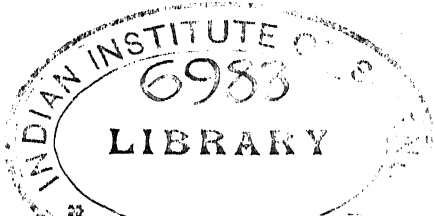
expected where the practice is followed of allowing each operator to make up his own mixture, as this tends to destroy uniformity and in many cases unsuitable mixtures will be used. It is a good plan to have a printed schedule placed in the hands of each shop superintendent and department foreman, showing the kind of coolants to use for all classes of work. Such schedules will show the formulas used by the man who has charge of making up oil mixtures, and in cases of trouble they will assist in determining whether the proper lubricant has been supplied for handling a given job. This practice will also be the means of reducing the consumption of lubricants and of obtaining lubricants that will give satisfactory results.

In mixing cutting emulsions and oils—particularly in cases where there is a lot of mixing to be done—equipment should be provided that will enable this work to be conducted with the least possible delay, and that will also guard against the loss of material that is bound to occur when buckets and other slipshod methods are used for handling various metals. An excellent arrangement of equipment for conducting mixing operations consists of a barrel located on the floor above the main storage tank from which lubricant is pumped to the gravity tank that supplies the various machines in the factory. Leading into this barrel there are a steam pipe and a water pipe, either of which may be opened to provide for boiling the ingredients of cutting emulsions or diluting them as required. Below the barrel is a valve connecting with a pipe leading to the storage tank; after the mixture has been made up this valve is opened to allow the lubricant to run into the tank.

Formulas for Homemade Cutting Emulsions. The following are formulas for cutting emulsions which well-known manufacturers have found very satisfactory. It will be noted that some of these are recommended for general application on those classes of work on which compounds give satisfactory results, while in certain other cases compounds are especially recommended for specific machining operations. In this connection, attention is called

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to the formulas for making emulsions that are given out by many oil manufacturers. Naturally these have especial reference to trademarked oils sold by these firms, and as they call for the use of these special ingredients, no mention is made of them in the following.

Soda-water mixtures are still used to a considerable extent, the advantage over plain water being that the rusting of tools or work is avoided by the addition of other ingredients. The following gives the formula for a soda-water mixture containing lard oil, which has a lubricating effect in addition to the cooling properties of pure soda water: Mix $\frac{1}{4}$ pound sal soda, $\frac{1}{2}$ pint lard oil and $\frac{1}{2}$ pint soft soap with enough water to make ten quarts. This mixture is boiled for one-half hour and is ready for use after cooling to normal temperature. This will give very satisfactory results for all classes of work on which cutting compounds can be used, except for drilling, and in this case the stock soda-water solution should be thinned down considerably to prevent foaming.

For general use in drilling, milling and other operations for which a cutting compound may be used, the following formula produces a coolant that will be found to give very satisfactory results: Take two galvanized iron buckets and fill one two-thirds full with No. 1 lard oil and the other two-thirds full with No. 1 screw cutting oil. To one pail add a pint measure of Proctor & Gamble's white soap chips and to the other pail add one-half pound of powdered soda. The contents of these two pails are then poured into a wooden barrel and thoroughly boiled with live steam which results in dissolving the soap and soda and thoroughly mixing it with the oil. After this has been done, the barrel is filled with cold water and thoroughly stirred to secure a uniform mixture, after which the contents are run into the storage tank of the central distributing station, from which pumps deliver it to circulating pipes leading to the machines in the factory.

For drilling and milling operations, the following formula gives a good cutting compound: Dissolve $2\frac{1}{2}$ pounds

soda ash in water and mix with 2 or 3 gallons lubricating oil. These constituents are thoroughly stirred to secure a uniform mixture and are then added to 40 gallons water.

For all milling, turning and drilling operations, the following formula produces a good compound: Dissolve $1\frac{3}{4}$ pounds sal soda in 10 gallons water and boil the solution with a steam jet, then add 1 gallon lard oil.

For reaming and tapping holes for staybolts one of the largest locomotive shops in the country uses a compound made up according to the following formula: Mix 18 gallons good grade lard oil, 60 pounds tallow and 100 pounds white lead.

To make a grinding compound, the following formula is highly recommended: Dissolve 75 pounds soft soap and 30 pounds sal soda in 15 gallons boiling water. Keep the mixture boiling and stir in 10 gallons lard oil. To this mixture add 1 ounce creosote oil as a disinfectant. When cool, mix 1 gallon of this stock solution with 3 gallons water to make the compound delivered to the wheel and work.

To make a cutting compound for gear-cutting with rotary cutters or hobs, the following formula produces an emulsion that gives excellent results: Stir together $3\frac{1}{2}$ gallons mineral lard oil and $2\frac{3}{4}$ pounds sal soda, and when thoroughly mixed add to one barrel of soft water. This compound does not thicken or leave a gummy residue.

Effect of Oil or Cutting Compound on Power Required to Drive Machine Tools. There is considerable diversity of opinion concerning the effect of oil or cutting compound on the amount of power required to drive the machine. Some investigators in this field have been unable to secure results that show any reduction of power consumption through the use of oil or cutting compound as compared with operating tools dry. Others have found a marked difference in favor of an oil or compound, and it seems reasonable to assume in cases where no improvement has been found that the tool was probably working on those classes of metals where fairly satisfactory results might be obtained without the use of a coolant. The following gives the experience

of one or two investigators who have found a cutting compound to be a valuable factor in reducing the amount of power required by the machine.

At the plant of the Bullard Machine Tool Co., Bridgeport, Conn., a machine was working on a steel casting which had about $\frac{3}{4}$ inch left on the diameter for machining. The surface to be finished was about 16 inches wide, and two large streams of cutting compound were delivered to the tools which were taking two cuts, one at the top and one at the side. The compound was delivered at the rate of about thirty-six quarts per minute directly to the tools, but even under these conditions the chips turned blue when they came out from the cutting compound. With a view to determining the effect of the compound upon the machine's power factor, the experiment was tried of shutting off the flow while the machine was in operation under the conditions mentioned. When this was done the machine made one-half revolution and then the belt went off. It was expected that the tools were either broken or burned, but an investigation showed that they were still in perfectly good condition because the machine had not run far enough to cause damage in this way.

After putting on the belt, the machine was started and continued to run satisfactorily until the flow of coolant was again shut off; then the machine went less than one-half revolution before the belt was again thrown off. This experiment was tried a sufficient number of times to show conclusively that there was a direct relation between the power factor and the cutting compound. With the view of obtaining definite information on this subject, the machine was provided with a motor attached to a recording watt meter, and with this equipment it was found that on heavy cutting there was a difference of as much as 43 per cent in the power required to machine a piece with and without the application of coolant to the tools. With machines working on smaller work and taking lighter cuts, less difference was found.

Further experiments conducted along the same lines showed that pieces machined without the use of a coolant

became so badly heated that they were difficult to handle, and the expansion and subsequent contraction had seriously affected the accuracy of the dimensions. For instance, a hole 15 inches in diameter when a piece was cold became 15.009 inches when a light facing cut was taken across the top of the casting, so that measurements made while the piece was hot had to be corrected for expansion, which was often a difficult matter. The elimination of such inaccuracies and the saving of power are of sufficient advantage to warrant the use of coolants in turning such materials as cast iron, where their use is not an absolute necessity.

Experiments conducted in England by Dempster Smith showed that where coolants were used in drilling with twist drills, using a feed of 0.040 inch per revolution, the torque was 72 per cent, and with a feed of 0.030 inch per revolution the torque was increased to 92 per cent of the value obtained when operating the drill dry. When machining soft, medium and hard steel, the respective thrusts were 26, 37 and 12 per cent less when a coolant was used than when the drill was operated dry, but no marked difference was found for different rates of feed, as in the case of the torque. Experiments conducted with boring-bars and trepanning tools showed the following relation of power consumption for different conditions of operation: Tool operated dry, relative power consumption, 1; pure water delivered to tool, relative power consumption, 0.91; soap and water delivered to tool, relative power consumption, 0.94; emulsion of oil and water delivered to tool, relative power consumption, 0.87.

Another investigator found that liberal use of a cooling medium on twist drills reduces end thrust by 35 per cent and torque by 20 per cent of the values secured when operating the tool dry, thus effecting a large saving of power as well as increasing the working efficiency and duration of sharp cutting edges for the drill.

Fire Hazard in Use of Cutting Oil. The use of water for cutting purposes, while quite desirable from a fire standpoint, was soon found to produce inferior results as

compared to oil, owing to the fact that for certain classes of work a greater measure of lubrication was desirable, and the water caused trouble by rusting the machines. The use of oil has therefore increased rapidly in the last fifteen years owing to the great development of high-speed tools, until at present the modern machine shop frequently contains large quantities of cutting oil pretty well exposed and distributed throughout the shop. This oil is used over and over again in circulating systems which may involve an individual pan or reservoir for the oil and a pump for each machine or a system of pipes through which the oil is carried back to a main storage tank and then forced by one large pump back into the system, feeding several machines.

The fire hazard which these large quantities of oil may present was strongly emphasized about five years ago, when a large machine shop was completely destroyed by fire. The building was not equipped with sprinklers and the construction was not of the best, but the rapidity with which the fire spread brought up the question as to whether the large quantities of cutting oil, which in that case contained a considerable proportion of kerosene, had not been an important factor in the rapid spread of the fire.

It was therefore decided to have the Inspection Department of the Associated Factory Mutual Fire Insurance Cos., 31 Milk Street Boston, Mass., conduct an investigation of the matter of cutting oil hazard, and the following information is taken from its report. This investigation has been conducted along three lines: First, a study by means of reports prepared by the regular inspectors of conditions in risks covering the amount and character of the oils used, the general conditions with respect to oil-soaking of the floors, use of sawdust, etc.; second, a laboratory investigation covering flash and fire points, spontaneous combustion tests and viscosity measurements of samples obtained from risks, and also of mixtures prepared in the laboratory; third, a series of fire tests to determine the hazard of oil-soaked wood, the readiness of ignition and spread of fires

in oil-soaked sawdust and steel chips, the ignition of oil in pans, methods of extinguishing oil fires, etc.

The amount of oil used varies considerably with the kind of machine, some using not more than four or five gallons, while a few of the large automatics use from thirty to fifty gallons. Ten gallons per machine, however, may be considered a fair average.

The majority of factories use the individual pumping system, in which a pump is provided for each machine. A few, however, have large systems in which one pump may supply fifty or more machines. In some mills both systems are used. Paradoxical as it may seem at first, it is believed that the multiple-feed system, where it can be properly arranged, is the safer. With this system it is possible to reduce materially the amount of oil in important buildings, as the storage tank and pump can be located outside. This arrangement, of course, requires more or less piping carrying oil, but this is believed to be less of a hazard than the presence of a large number of open oil pans.

Splashing and Oil-soaking of Floors. From a study of the conditions in several plants, it became evident that there is a wide difference in the amount of oil which gets on the floor. Some shops have made a special study of guards for catching oil and preventing it from reaching the floor, while others have apparently paid no attention whatever to this matter. One shop did a piece of investigation work that showed unusual interest in solving this problem. A machine was set up in an open space where it could be easily observed and blotting paper was placed all around it on the floor. The foremen of the different departments were then assembled, and the machine was started. Each man was instructed to watch a certain part of the floor, and whenever a drop of oil struck, it was traced back to the point from which it came, and a guard was constructed to catch this oil. By this means the machine was completely guarded, so that it threw no oil whatever on the floor. This process was repeated with the different types of machines in the plant, resulting in a clean shop

with practically no oil on the floor, greater economy and much safer conditions as respects fire hazard.

The manufacturers of machine tools make guards to be used with their machines but these are often sold separately and are ordered in only a few cases by the purchasers of the machines. It is undoubtedly true that it is impossible to guard some machines completely without interfering with the operation, but nevertheless there is room for a great deal of improvement over present conditions.

A frequent offender in the splashing of oil on the floor is the pump where the individual feed is used. The pumps are sometimes placed at one side of the oil pan of the machine, and as the stuffing-boxes frequently leak, they throw large quantities of oil on the floor. The pump should always be placed over the pan of the machine, and properly guarded to prevent splashing. Another frequent source of trouble is the carelessness of the workmen in handling finished pieces dripping with oil.

Probably little can be done in the way of improvement that would require much cooperation on the part of the workmen, but it is possible to improve conditions, at least in some plants, with respect to the receptacles in which the finished pieces are placed, both as regards their character and location, so as to reduce the amount of dripping to a minimum. The receptacle should be oil-tight, and should be placed as close to the machine as practicable. A sheet-iron drain or trough should also be provided between the machine and the box, so that the finished pieces would normally be conveyed over this drain from the machine to the box. These precautions are necessary only in cases where the finished work comes in contact with large quantities of oil, and has no opportunity to drain in the machine before being removed.

Use of Kerosene in Cutting Oils. The practice of adding kerosene to cutting oils, which has developed in the last few years, has been resorted to for one or more of the following reasons: First, to obtain a cutting oil which will cool the work and tool rapidly, and carry the chips

away quickly, but which will still possess considerable lubricating value; second, to cheapen the cost of the cutting medium; third, to prevent gumming or thickening of the cutting oil.

It is clear that the addition of kerosene at a comparatively low price results in a material reduction in the cost per gallon of the cutting oil. The actual reduction in price, however, is less than would appear at first thought, as kerosene evaporates appreciably at room temperatures, and it is generally necessary to add more kerosene from time to time, while with the straight cutting oils, or cutting oils thinned with light mineral oils, this evaporation is practically negligible. The amount of kerosene added varies widely, ranging from 3 to 75 per cent.

In a few special operations, such as cutting aluminum, there appears to be a firmly fixed idea on the part of some manufacturers that nothing but straight kerosene can be used. There is no doubt but that the cutting of aluminum presents difficulties not found with steel, but one large manufacturer of machine tools has found it possible to use an emulsion for cutting aluminum with entirely satisfactory results.

From a careful investigation of the matter, both by means of laboratory tests and a study of conditions in different risks, the conclusion has been reached that the use of kerosene is not necessary in any case for cutting metal with the possible exception of aluminum. The kerosene has but slight lubricating value, and acts merely as a diluent to thin down the oil. This reduction in viscosity is undoubtedly necessary for some purposes, but can be effected by using light mineral oils of high flash point. Thus a shop, which has been using 25 per cent kerosene and 75 per cent lard oil, can prepare a satisfactory substitute by mixing about 40 per cent extra light spindle or transil oil with 60 per cent lard or mineral lard oil. This mixture will have a much higher flash point than that containing kerosene, and will have approximately the same viscosity and lubricating efficiency.

In extreme cases where it is absolutely necessary to have a very thin oil the kerosene may be replaced with 300-degree fire test oil. By using this product it is possible to obtain mixtures with practically as low viscosities as the kerosene mixtures having up to 50 per cent kerosene, but which have materially higher flash and fire points. It is believed, however, that it is necessary to resort to 300-degree oil only in a few cases.

In cutting aluminum some manufacturers have claimed that straight kerosene or a mixture containing a large proportion of kerosene is necessary. On the other hand, one large manufacturer of machine tools and measuring instruments has used an emulsion for cutting aluminum with entirely satisfactory results. Even though emulsions do not prove generally satisfactory for this purpose, there is little doubt but that the 300-degree fire test oil could be used in place of kerosene.

Tests were made on oil-soaked mixtures of sawdust and bicarbonate of soda containing varying proportions in order to determine the effect of the bicarbonate of soda on the combustibility of the sawdust and oil. The following mixtures were prepared, the proportions being by weight:

No.	Sawdust, Parts	Bicarbonate of Soda, Parts	Lard Oil, Parts
1.....	100.....	20.....	100
2.....	100.....	100.....	100
3.....	100.....	100.....	200
4.....	100.....	200.....	200

In sample No. 1 the bicarbonate of soda produced no visible effect on the combustibility of the mixture. In No. 2 the combustibility of the mixture was considerably retarded, but the amount of oil in this combination was considerably less than is generally found in sawdust before it is considered sufficiently saturated to warrant removal. No. 3, where the quantity of oil was doubled, and which still contained less than is frequently found in oil-soaked sawdust in mills, burned freely; the same was true of No. 4. It is evident from these tests that no amount of bicarbonate

of soda, which could be used at a reasonable cost, would have any important effect on the combustibility of oil-soaked sawdust.

Type of Feed System. The multiple-feed system for supplying cutting oil to machines when properly arranged is preferable to the individual feed. With the multiple feed it is possible to locate the main storage tank outside of important buildings and therefore greatly reduce the amount of oil inside the buildings. This advantage, it is believed, more than offsets the objection to the introduction of oil-filled pipes in buildings.

Prevention of Oil Splashing. A great deal of improvement is possible in the matter of preventing oil from getting on the floor by the provision of proper oil guards. In some classes of automatic machines it is not possible to keep all the splash from reaching the floor, but in many cases this can be done, and in all cases the greater part of the splash can be caught. Oil-tight receptacles for the finished pieces should be provided, and these should be located as near the machine as practicable. Drains or troughs should also be arranged to catch the drip when the pieces are being conveyed from the machine to the box. The pumps on individual feed systems should be given attention by locating them over the oil pans, and keeping the stuffing-boxes in good condition, or providing adequate guards.

Starting of Fires. The hazard resulting from the use of large quantities of cutting oils depends to a considerable extent on the character of the oil and the condition of the floor. If a straight cutting oil is used, a fire cannot be readily started with a match or a small quantity of burning waste. Where straight cutting oil has leaked through from the floor above to the ceiling, a fire can be started from a comparatively small source, whereas without oil no fire would result from the same cause. Fires could not be started from a match or small quantity of oily waste on floors, even where the floors were covered with as much as 50 per cent of kerosene mixed with cutting oil. In ceil-

ing tests the oily wood ignited much more easily when kerosene was used than when it was absent, the ease of ignition being proportional to the percentage of kerosene present.

Spread of Fires. The tests showed clearly with what difficulty a small fire spreads in a horizontal direction on the top of a floor, even though the wood is oil-soaked with a mixture containing a considerable proportion of kerosene. This is purely a result of unfavorable draft conditions. The draft from such a fire is inward and upward so that the heat does not reach the wood or oil to raise it to the flash point. If, however, as the result of the presence of other readily combustible material a fire of any size is started, the presence of oil-soaked floors is undoubtedly an important factor in producing a hot fire and increasing its spread. Where the oil-soaked wood is in a vertical partition, a fire does not develop very rapidly from a small source unless there is an open space under the partition to furnish a good draft. The effect of the kerosene on the partition, however, is very definite and marked, the height of the flames being dependent on the percentage of kerosene. Fires on the under side of a ceiling spread without difficulty. This is due to the fact that the heat from the fire comes in contact with the wood immediately adjacent to the flame and heats it up to the flash point. Here again the spread of the fire is in proportion to the percentage of kerosene.

Fire in Open Pans. In open pans where straight cutting oils of a high flash point were used, the oil could not be ignited from a fire of small size such as fifty grams (approximately two ounces) of cotton waste. Where kerosene was used, however, a fire could be started with the same quantity of waste and spread rapidly. The ease of ignition of the kerosene-cutting-oil mixture depended on the percentage of kerosene.

Fire in Oily Steel Chips. The presence of steel chips on the floor or in pans aids materially in igniting the oil and spreading the fire. In pans containing steel chips and

a mixture with a large percentage of kerosene, it was possible to ignite the oil with a match, whereas with smaller percentages of kerosene this could not be done.

Fire in Oil-soaked Sawdust. The use of sawdust on floors for absorbing cutting oils greatly increases the fire hazard. Where a straight cutting oil is used, a fire can be started in the oil-soaked sawdust with a match, although it does not spread rapidly. If the oil contains kerosene, however, fires can be easily started by means of a match and spread very rapidly, particularly where a large percentage of kerosene is present. When the cutting oil contains over 60 per cent of lard oil, there is a possibility of spontaneous ignition of the sawdust under favorable conditions. The use of bicarbonate of soda mixed with sawdust in any quantity, which would not be prohibitive in cost, does not materially affect the combustibility of the oil-soaked sawdust.

Extinguishers for Cutting-oil Fires. For extinguishing cutting-oil fires in pans, sawdust and bicarbonate of soda were found as efficient as any other material. In cases where large pans or several pans were involved, the sawdust and bicarbonate of soda could not, of course, be used, but such fires would have then passed outside the field of hand apparatus.

Use of Emulsions. The use of emulsions in place of cutting oils could undoubtedly be greatly extended in many plants by adopting emulsions especially compounded according to the character of the work in hand. The increased use of emulsions would result in a material reduction in the fire hazard and in the cost of lubrication.

Elimination of Kerosene. The use of kerosene cutting oils does not appear to be necessary under any conditions with one possible exception. This exception is in the cutting of aluminum, but even here the matter is open to question. Two or three manufacturers claim that kerosene is the best for this purpose but, as mentioned on page 38, one large manufacturer of machine tools and measuring instruments uses an emulsion with entirely satisfactory results.

The chief function of kerosene is as a diluent to reduce the viscosity of the cutting oil. This object can be attained by using the proper amount of light spindle oil, or in extreme cases by adding 300-degree fire test oil. In no cases, it is believed, should oil for general cutting purposes have a fire point of less than 300 degrees F., and in the great majority of cases it can be higher. That the use of kerosene can be eliminated is shown by the fact that since this investigation was started, a number of shops have, without interfering with the efficiency of their plants, given up the use of kerosene.

CHAPTER III

DISTRIBUTING SYSTEMS FOR MACHINE TOOLS.

THERE are a variety of methods of delivering oils and compounds to cutting tools, and each has its particular field of application. These methods vary all the way from the use of a squirt can or brush, with which the cutting compound is applied to the tool, up to a central distributing station equipped with pumps for delivering oil through pipe lines to all the machines in the factory, a system of piping for returning the coolant, and filters and sterilizers for purifying the returned oil. The squirt can and brush are still used in certain cases for small taps, end mills, threading tools, etc., and for this purpose give fairly satisfactory results. The next step in the development of methods of supplying coolants consists of a small drip can, mounted on the machine, from which oil or cutting compound is allowed to trickle by gravity to the tool and work. These cans are usually provided with a wire gauze strainer to remove chips and suspended impurities from the coolant. After flowing over the work, the coolant is caught in a second can, suspended under the machine, and from time to time its contents are poured back into the drip can ready for subsequent use. Various methods are used for suspending drip cans on machines in order to provide adjustment for delivering the fluid to the required position, and Fig. 3 shows three typical examples. At *A* it will be seen that the can is mounted on a jointed bracket, which can be swung on its pivots to bring the can and delivery pipe into the desired position. The can shown at *B* is carried by a fixed bracket, but the delivery pipe is jointed to afford adjustment. At *C* the can is suspended on a bracket held by a vertical rod in a split clamp, providing both vertical and horizontal adjustment of position. Methods of this kind for supplying oils and com-

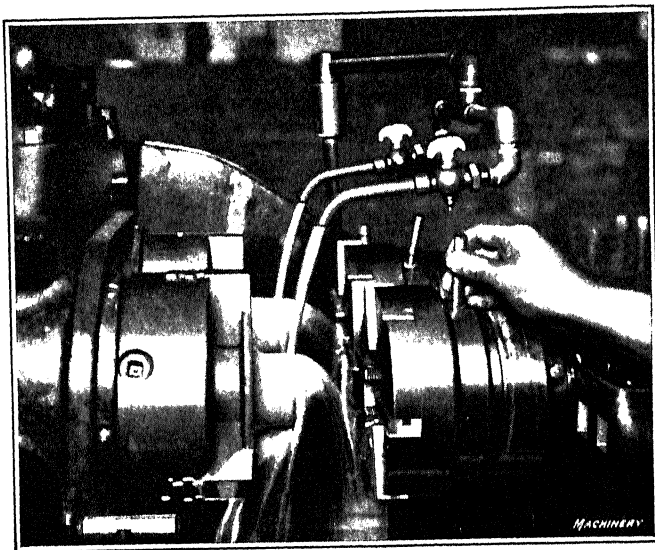


Fig. 1. Method of delivering Coolant to Threading Dies

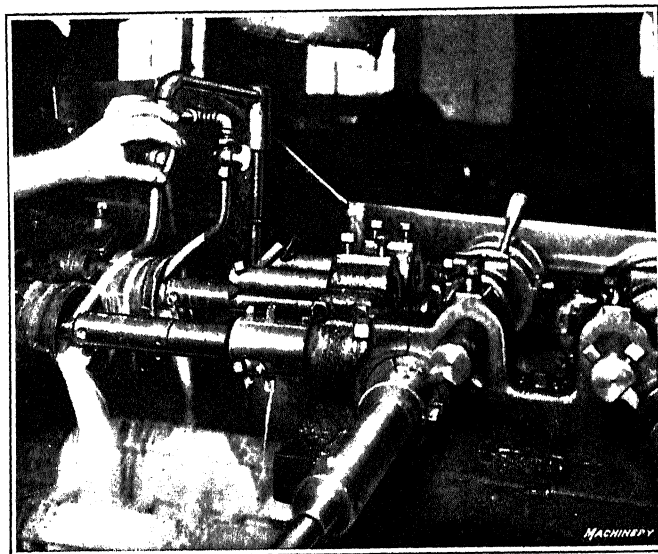


Fig. 2. Delivery Tubes adjusted to deflect Flow of Coolant into Work

pounds are still used in factories where the tools work under such conditions that the coolant need not be delivered in large volume. The only advantage of such methods is that they are inexpensive.

Provision of Individual Pumps on Machines. When a considerable volume of oil or cutting compound is required for the work, the drip can is unsatisfactory, due to the necessity of frequently emptying the can. This led to the development of individual pumps for use on machine tools. Four typical classes of pumps are used for this purpose, and these are (named in the order in which they are most generally applied) the geared, wing, plunger and centrifugal types. Each of these will be described in detail under individual headings. In all cases, too much emphasis cannot be laid upon the

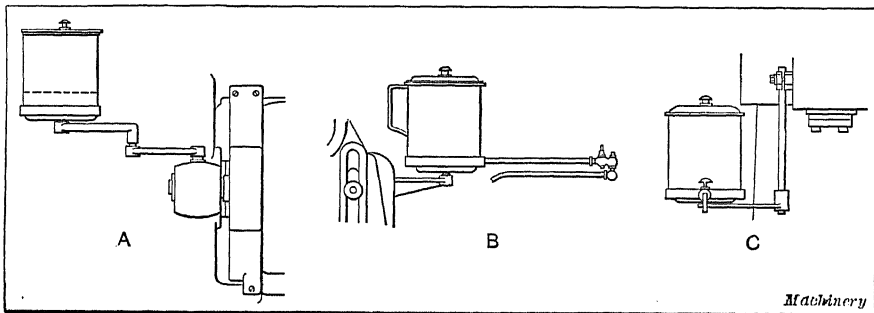


Fig. 3. Three Methods of supporting Drip Cans which afford Adjustment of Position for Delivery Pipe

necessity of having the pump and delivery pipe of ample capacity to supply a copious flow of coolant to the tools and work. The average size of delivery pipes on machine tools runs from $\frac{1}{4}$ to $\frac{3}{4}$ inch, but the latter should be made the minimum and means provided to regulate the volume of coolant delivered by the pump according to the requirements of the work. Many cases of failure to secure satisfactory results are due to the inability of the pipe to deliver the required volume of coolant at low pressure, rather than to the unsuitability of whatever oil or compound is used. A large delivery pipe provides for the delivery of a copious flow at low pressure, which is the ideal condition, as regards both the cooling and lubricating action of the fluid.

In addition to the importance of keeping down the temperature of oils and compounds so that they may exert the desired cooling

action upon the tools, low temperature is of great importance from the standpoint of pump efficiency. If the temperature is allowed to rise to such a degree that vapor is given off from the fluid, it is likely to interrupt the pump suction. In order to be sure of efficient operation of pumps it is also necessary to keep the inlet to the suction pipe well below the surface of the reservoir. This is also a matter of importance due to the fact that drawing air into the pipe

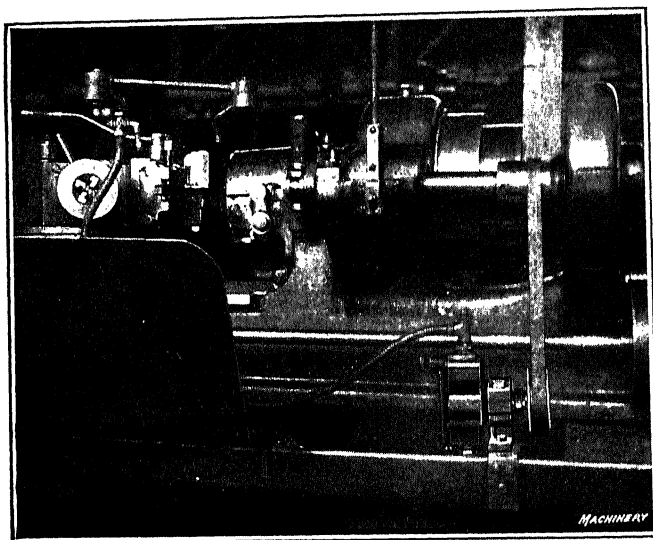


Fig. 4. Geared Pump in Use, showing Method of mounting, driving and delivering Coolant to Work

may cause oxidation of the oil which produces a sludge that will tend to clog the pipes and give trouble in other ways.

The Geared Pump. The most common form of pump used on machine tools equipped with a tank and pump, consists of the rotary geared pump which is so well known that it requires little description. The pumps can be made to deliver coolant when running in either direction, thus adapting them for use on machines where reversal is required to back off threading dies, etc.

Several methods are used for driving geared pumps, the most common of which is by a belt from the countershaft or

a pulley on the machine, or by direct-connected gearing. The claims made for the geared type of pump are that it affords a positive pressure without fluctuation in the rate of delivery. In pumps of this type provision is made against loss of prime so that any liquid from water up to the heavier oils may be easily pumped without the necessity of priming the pump. The compact form of these pumps is a point in their favor.

One of the geared pumps is illustrated in use in Fig. 4; and Fig. 5 shows the mechanism of this pump. Reference to the latter illustration shows that the coolant drawn

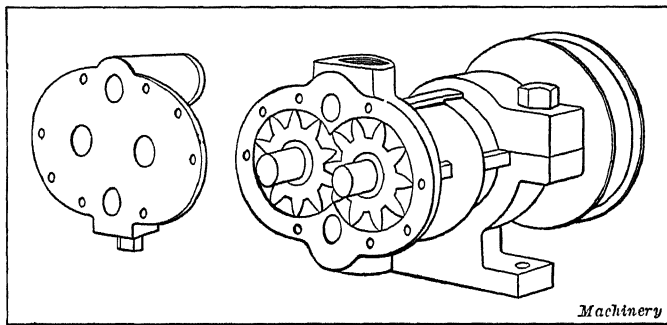


Fig. 5. View of Geared Pump showing Arrangement of Gears

through the suction pipe is carried around in the spaces between the gear teeth and the pump chamber. This coolant is forced out through the discharge pipe to the tools on the machine. To obtain the best results, the pump should be placed as near as possible to the level of the cutting compound in the tank. This type of pump is capable of working with a suction lift of from three to four feet without priming, and will develop considerable pressure when necessary for washing away chips. A by-pass is provided in the pump to enable the operator to regulate the volume of fluid delivered. To give an idea of the capacity of these pumps it may be mentioned that the Goulds Mfg. Co., Seneca Falls, N. Y., builds geared pumps in two sizes which are known as Nos. 1 and 2. Operating at speeds of from 200 to 500 revolutions per minute, the No. 1 pump has a capacity for from one and

one-half to four gallons per minute, working through suction and discharge pipes $\frac{1}{2}$ inch in size; under the same conditions of speed the No. 2 pump has a capacity for delivering from four to ten gallons per minute when working through $\frac{3}{4}$ -inch suction and discharge pipes.

Wing Type of Pump. Fig. 6 shows two examples of the wing type of pump which is used extensively on machine tools. This pump consists of a revolving stem which is set eccentric to the bore of the pump chamber, thus leaving a space at one side which contains the fluid being pumped. This type of pump delivers a large volume of oil when running at about 100 revolutions per minute, and on account of

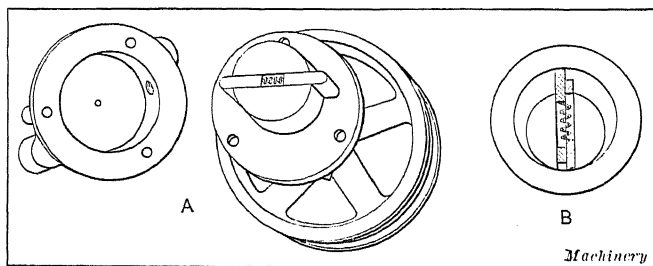


Fig. 6. Two Styles of Wing Pumps; at B is shown Means of obtaining Pressure Relief

this low speed it requires very little attention. It will be seen that the revolving stem is slotted to receive a pair of flat plates or wings which are forced apart by springs. As the stem rotates, the ends of these wings remain in contact with the inside of the pump chamber, thus drawing fluid in and discharging it in one direction or the other according to the direction in which the stem rotates; this makes the wing type of pump suitable for delivering coolant to tools on automatic screw machines, etc., where reversal of direction of rotation is often necessary. Pumps of this type will develop sufficient suction to lift fluid a slight distance, but it is better practice to have the pump submerged in order to avoid the necessity of priming. In the type of pump shown at B in Fig. 6, it will be noted that the wings are tapered at the ends so that when a full discharge is not required, pres-

sure of the liquid will force the wings back, thus making a relief or overflow valve unnecessary. The simplicity of all parts of wing pumps enables them to run for a long time

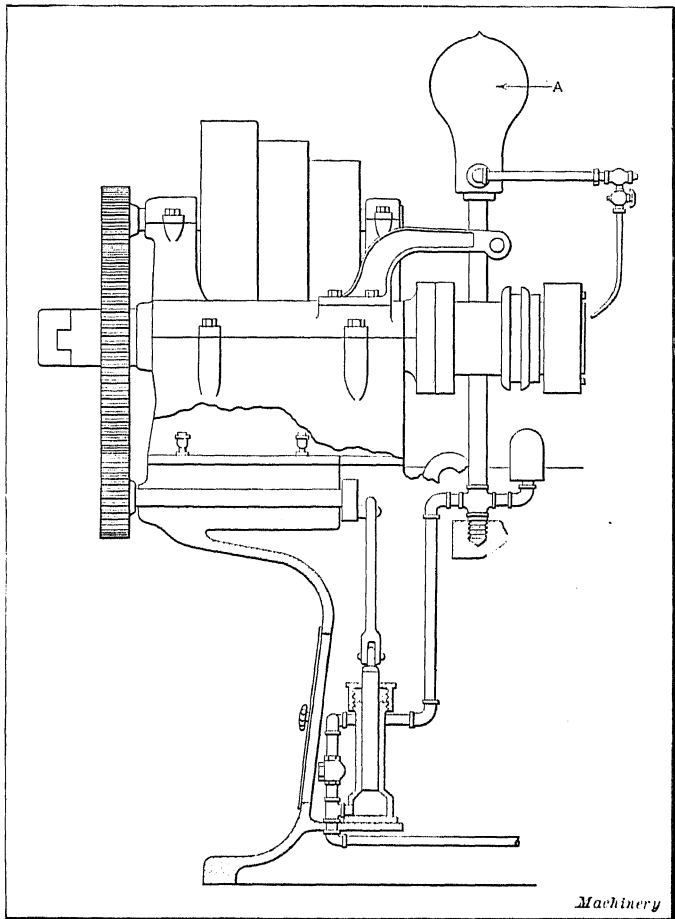


Fig. 7. Use of Plunger Pump on Bolt Threader

without getting out of order. The same methods are employed in driving these pumps as in driving geared pumps.

Reciprocating or Plunger Type of Pump. Fig. 7 illustrates the use of a plunger pump for circulating oil or cutting compound on a bolt cutting machine made by the

National Machinery Co. of Tiffin, Ohio. Pumps of this kind are used in various sizes and with different numbers of cylinders according to the volume of cutting compound to be delivered. In the case illustrated the pump has an adjustable stroke to provide for varying the volume of coolant delivered to the tools, and a safety overflow valve relieves back pressure in case the valve on the spout is closed while the machine is in motion. To avoid "pulsations" which would otherwise result from the use of plunger pumps, it is good practice to insert an air bell *A* in the delivery line which forms a cushion that takes up inequalities in pressure. In the case of multiple plunger pumps the cranks are equally spaced around the crank circle so that the variations of pressure in the cylinders tend to compensate for each other. This condition is shown diagrammatically in connection with the description of plunger pumps for central distributing stations.

In the plant of the Crucible Steel Co. of America at Harrison, N. J., triplex plunger pumps, 4 by 6 inches in size, with capacities for displacing forty gallons of oil per minute, are used for cooling tools on shell boring lathes. One pump is used for two machines, the pump and coolant supply being contained in a pit in the concrete into which the oil or compound is returned after being strained.

Centrifugal Type of Pump. As the name implies, the operation of centrifugal pumps is based on the action of centrifugal force. They are provided with an impeller which consists of a wheel having passages into which fluid is drawn from the suction pipe, carried around inside the pump case and expelled into the discharge pipe through the action of centrifugal force. An important point in their favor is that these pumps are capable of delivering a large volume of fluid at low pressure.

The Fulflo Pump Co., Blanchester, Ohio, makes a small centrifugal pump, shown in Fig. 8, for delivering oil or cutting compound to tools where an individual distributing system is used on each machine. The important features of this pump are that at no point is the channel through which coolant passes smaller than the $\frac{3}{4}$ -inch suction and delivery

pipes, and hence there is practically no chance for the pump to become clogged. Small chips and grit carried by the fluid will not damage this pump, and there are no parts that are likely to get out of order. Also, the design is such that the pump cannot lose its prime, as both inlet and outlet are above the pump level and there is always enough fluid in the pump to start it. The coolant is drawn in through suction pipe *A* and finds its way into the impeller through spaces *B* around the bearing; then the impeller expels the fluid into the delivery pipe *C*. To regulate the flow it is merely neces-

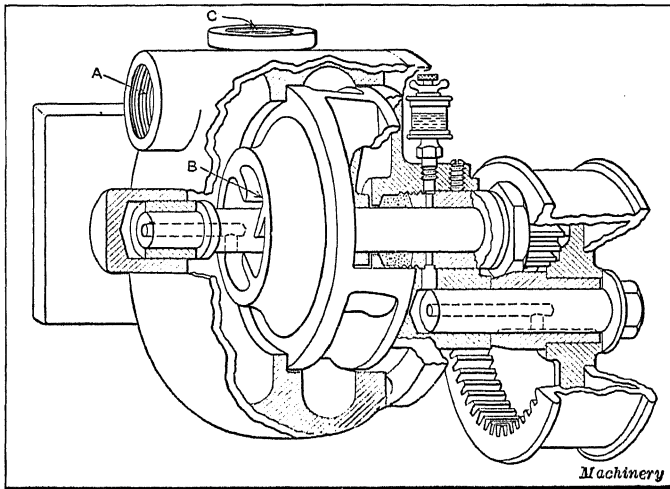


Fig. 8. "Fulflo" Centrifugal Pump

sary to open or close a stop-cock at the outlet; with this exception there is no valve in the pump or piping. The operator does not need to leave his work to regulate the flow of coolant. The following gives the capacity in gallons per minute for different pump pulley speeds when operating under a suction lift of 12 inches and a head lift of 4 feet, which is about the maximum requirement for machine tool installations: 300 R.P.M., 5 gallons; 350 R.P.M., 10 gallons; 400 R.P.M., 15 gallons; 450 R.P.M., 18 gallons. To obtain a greater volume for these suction and head lifts or the same

volume for increased lifts, it is simply necessary to increase the pump pulley speed.

When the design does not prevent loss of prime, it is good practice to have the pump submerged in the reservoir to avoid the necessity of priming. On grinding machines where this practice is followed, running bearings should be protected from gritty water. On milling machines built by the Cincinnati Milling Machine Co., where flooded lubrication is required, centrifugal pumps are used that are capable of delivering eleven gallons of cutting compound when run-

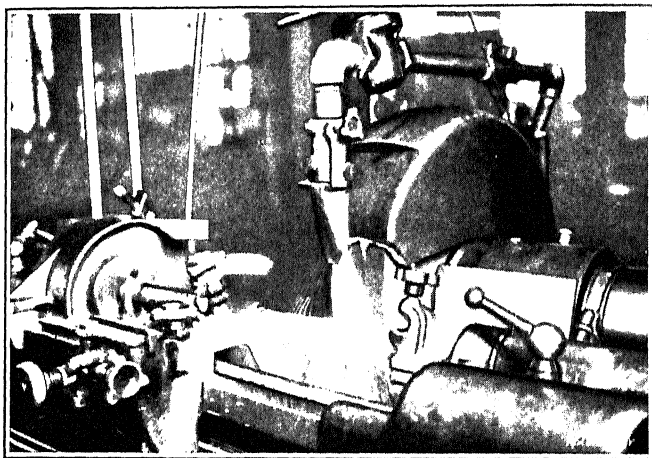


Fig. 9. Adjustable Deflector for delivering Coolant to Grinding Wheel and Work

ning at 1150 revolutions per minute. This washes away the chips.

Positive Pump Pressure and Gravity Feeds. Two systems are in general use for delivering oils and compounds from a central station to machines in the shop. One of these consists of pumping the purified coolant up to a storage tank at the top of the building from which it flows by gravity to the machines on different floors. The other is to pump the coolant directly to the different machines. Each system has its advocates and each seems to have certain points in its favor. The claim is made for the gravity tank system that a uniform pressure is obtained for the oil, without fluctua-

tions due to pulsation of the pump. It is also pointed out that should the pumps fail, there is a supply of oil in the gravity tank that will carry the machines for a limited

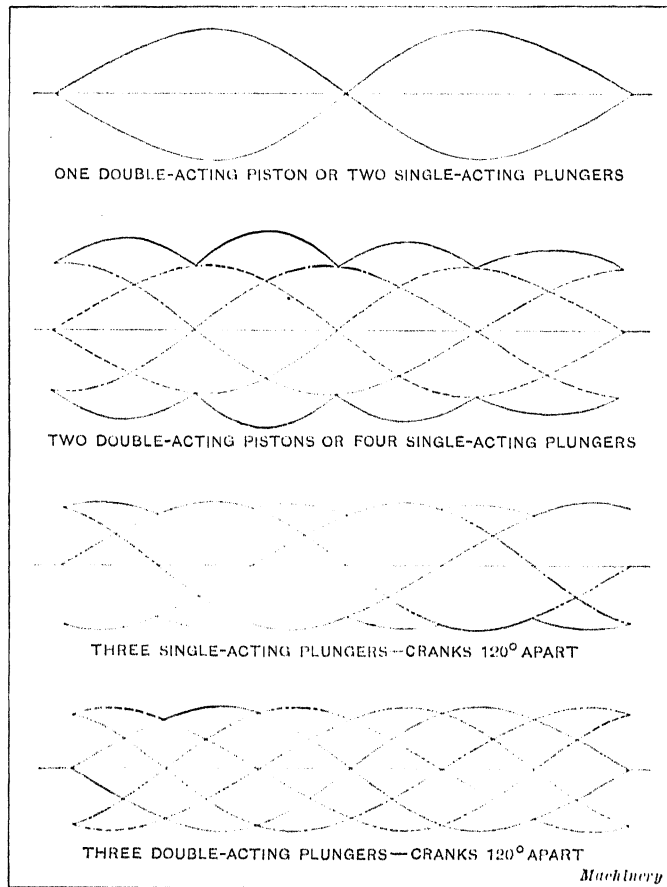


Fig. 10. Diagram Illustrating how Plungers of Multiple-plunger Pump tend to neutralize Variations of Pressure in Different Cylinders

space. This may be a point of some importance, but the claim made in regard to variations of pressure due to pulsation is not so important as will be seen by reference to Fig. 10, which shows how each cylinder in a triplex pump, which is one type commonly used for this service,

tends to neutralize variations in pressure in the other two cylinders, so that the combined effect is a close approximation of normal pressure.

Regardless of whether a gravity tank or direct-pump delivery is employed, it is necessary to keep the pressure of coolant delivered to machines on different floors as nearly uniform as possible, and this result is secured by having valves placed in the pipe lines on each floor or supplying individual valves at each machine. For average work, the pressure in the pipe line is usually maintained at from 28 to 30 pounds per square inch. The valves at the machines can be adjusted to throttle down the pressure to exactly the required amount. In cases where a variety of machines on the same floor call for delivery of oils or compounds at different pressures, it is common practice either to have a number of valves in different branches of the pipe line leading to the different classes of machines or to provide an independent valve on each machine.

Return of Coolant to the Central System. After flowing over the tools and work the coolant is collected by the usual means provided on machine tools and returned through drain pipes to troughs in the floor. These are covered with boards that may be lifted to give access to the trough, when this is necessary. The troughs are usually about 6 inches wide by 1 foot deep, the size depending on the amount of coolant to be handled, and it may be mentioned that troughs are used in place of pipes to prevent the system from becoming clogged by chips or through gumming of oil. In buildings with concrete floors these troughs may be placed in the concrete, but if machines are carried on wooden floors the drain pipes can pass through the floors and discharge into galvanized-iron troughs suspended from the ceiling of the room below. An advantage of having all the oil handled from a central station is that it reduces fire hazard, as no oil is kept in the base of the machine and the small quantity adhering to chips is insufficient to support a fire. The oil storage and filter can be located away from the main building or, if this is not considered desirable, it can be put in a fireproof compartment.

Pumps used in Central Station Practice. Pumps used for distributing oils and cutting compounds from central stations are usually of either the plunger or centrifugal type, and each of these has points in its favor. The following

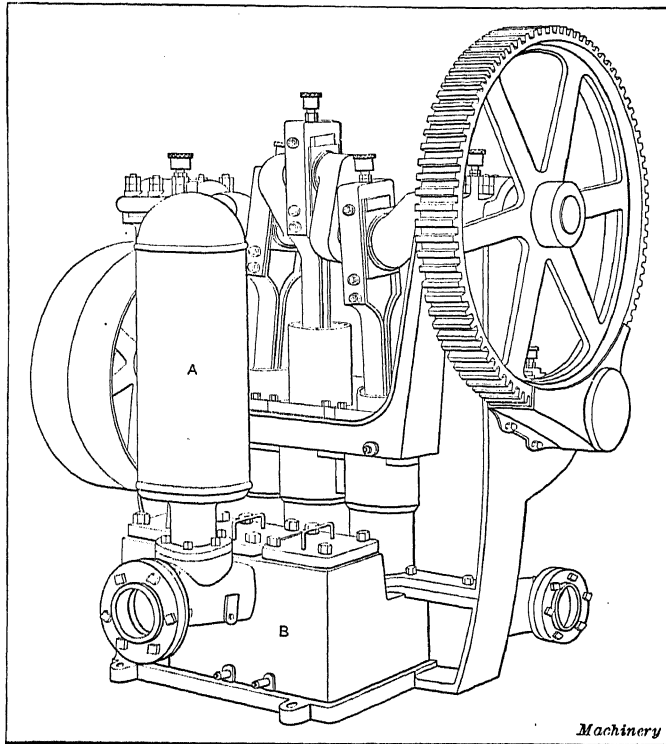


Fig. 11. Single-action Triplex Plunger Pump

gives a brief description of the reciprocating or plunger type of pump:

Fig. 11 illustrates a single-acting triplex plunger pump built by the Goulds Mfg. Co. These pumps are ordinarily driven by individual electric motors. The pumps are geared down so that the pump speeds vary from about 40 to 60 revolutions per minute. When delivery of a large volume of cutting compound is required, pumps with three plungers are used in order to secure uniformity in pressure

and rate of delivery. In Fig. 11, *A* is an air chamber against which the pressure is developed, the air acting as a cushion to absorb shock and help to maintain the pressure at a uniform level. In case *B* are contained inlet and discharge valves for each of the cylinders. Pumps of this type are made in sizes ranging from 8¼ by 10 inches down to 4 by 4 inches, with capacities from 30 to 400 gallons per minute. Any desired pressure may be maintained by means of a by-pass and pressure regulating valves that can be set to give the required pressure.

Centrifugal Pumps. The operation of centrifugal pumps is based upon the action of centrifugal force. Pumps of

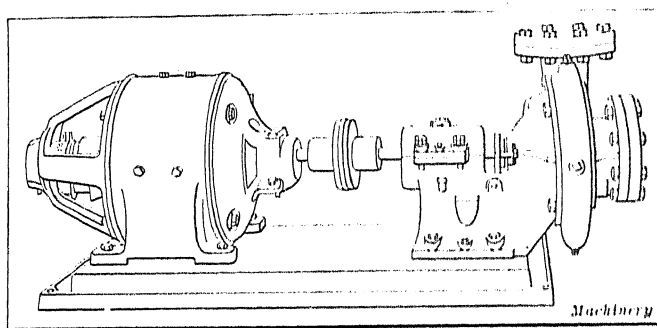


Fig. 12. Goulds Centrifugal Pump with Direct-connected Electric Motor Drive

this type are usually run direct-connected to an electric motor, as shown in Fig. 12, and oil or other fluid comes to the pump through a suction pipe. In starting the pump it is usually necessary to prime it or, in other words, to fill the suction pipe and pump casing with fluid. The impeller consists of a wheel with passages formed in it in such a way that the fluid enters from the suction pipe at points near the center of the impeller and is expelled from the periphery into the volute chamber. This volute chamber connects the pump with the delivery pipe. Various arrangements are used for priming pumps, one of the most convenient of which is to use a foot-valve in the suction pipe and have a pipe connection with the delivery pipe so that by opening a valve the suction pipe and pump casing may be filled. In other

cases hand pumps are used to raise the fluid in order to fill the suction pipe and pump casing.

Centrifugal pumps have one important advantage where coolant is delivered to all machines from a central distributing station in that they may be designed to deliver the oil at a specified pressure at the tools, and when this pressure is reached the pump will continue to "churn" without increasing the pressure. Large centrifugal pumps are usually built according to specifications of the purchaser and are arranged to develop a given pressure. Where pumps of this kind deliver coolant to tools on several floors and it is required to have the same pressure on all floors, the usual method of procedure is to design the pump to deliver the required pressure on the top floor; on lower floors where there is less loss of pressure due to a smaller static head and friction loss in the line, gate valves can be used to throttle down the pressure so that it will be the same as on the top floor. The same practice is used with other types of pumps; but in the case of plunger pumps it is necessary to have a pressure-control valve and by-pass, as previously mentioned. In addition to their application for distributing coolants from a central station, centrifugal pumps are employed on grinding machines and other machinery for pumping cutting compound to the wheel and work.

Delivery of Oil or Compound to Tools on Moving Carriages. Provision of piping to deliver oils and compounds from the pump to the cutting tool is most easily taken care of in those cases where no adjustment is required to take care of feed movements, etc. It frequently happens, however, that the tool carriage has to be traversed through a considerable distance, which necessitates special means for delivering the coolant to the work. One of the simplest methods of handling this problem is to use a flexible metal tube to connect the moving carriage and the supply pipe on the machine, and this gives very satisfactory results, except that when the tube is very long and in an exposed position, it is likely to get in the operator's way.

In many cases telescopic tubes may be used which furnish the necessary compensation for the movement of the tool

carriage. In the case of a rifle barrel drilling machine considerable compensation is required because of the long feed motion of the carriage. This compensation is furnished by telescopic tubes. In order to be effective in washing chips out of the hole, oil must be delivered to the barrel drills at a pressure of about 800 pounds per square inch. In some cases this pressure causes trouble by throwing the carriage back with great violence when the half-nuts on the lead-screw are released to return the carriage while there is still

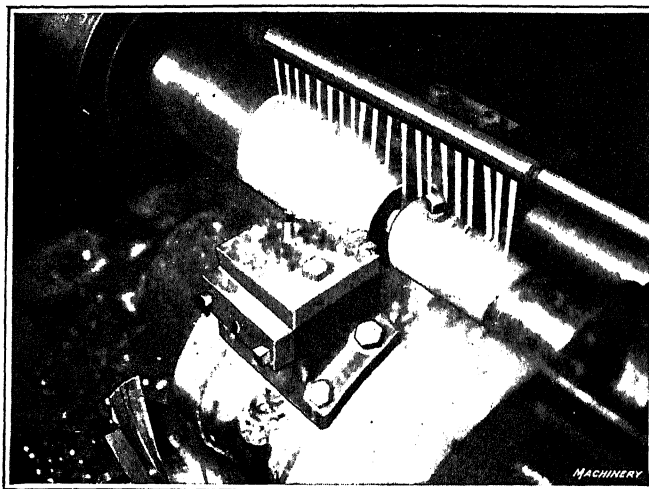


Fig. 13. Pipe with Series of Holes to distribute Coolant to Tools on Shell Turning Lathe

pressure in the tube. The machines may be equipped with a spring at the end of the machine bed to absorb shock when the carriage is accidentally thrown back in this way, but in many cases the effect of the spring is insufficient to give the desired result. To overcome this difficulty a rather ingenious method was developed. Instead of telescopic tubes being used, oil is delivered through a small tube connected with the oil supply; this tube runs the entire length of the bed and is capped at the right-hand end. Sliding over this tube is a larger tube with a stuffing-box at each end and a connection at each end to provide for passing oil to the tube supported in the machine carriage. Oil escapes through a

hole in the inner tube into the outer tube and thence to the carriage; and the pressure inside the larger tube is balanced in all directions so that there is no danger of the carriage being thrown back through pressure remaining in the tube when the half-nuts are released from the lead-screw.

Nozzles and Distributing Devices. The efficiency of the results obtained in cooling and lubricating cutting tools is largely governed by the form and size of nozzle through which the cutting compound is delivered, the direction and position in which it is applied, the pressure at which it is delivered, and the volume of fluid applied to the tool and work. If one or more of these factors is defective, it may be the cause of unsatisfactory results. The size of the coolant delivery nozzle is important because this governs the volume delivered at a given pressure, and the form of nozzle is responsible to a large extent for the manner in which the coolant is distributed over the tool and work. In all cases the aim should be to deliver the fluid in such a way that it will keep a constant supply at all points on which the tools are working, and this volume should be ample to provide for cooling the tools and work and prevent the cutting compound from becoming too warm.

Proper Direction in Which to Deliver Fluid. In early experiments conducted by F. W. Taylor in the use of a stream of water for cooling cutting tools, the first plan adopted was to deliver a stream of water up between the clearance flank of the tool and the work so that the water would almost reach the cutting edge of the tool at the point where the greatest cooling action was required. Mr. Taylor was so confident of the soundness of this theory that he did not at first deem it worth while to experiment with throwing streams of water in any other way, but some months later he tried the plan of throwing a stream of water upon the chip directly at the point where it was removed from the work, and found that a material increase in cutting speed could be employed under these conditions. In applying water in this way for cooling tools used in the performance of manufacturing operations, Mr. Taylor found that when a sufficiently heavy stream of water was thrown upon the

work to give the desired cooling action, it had a tendency to splash more than when thrown upon the forging just above the chip, and to avoid discomfort mechanics would change the position of the delivery pipes unless care was

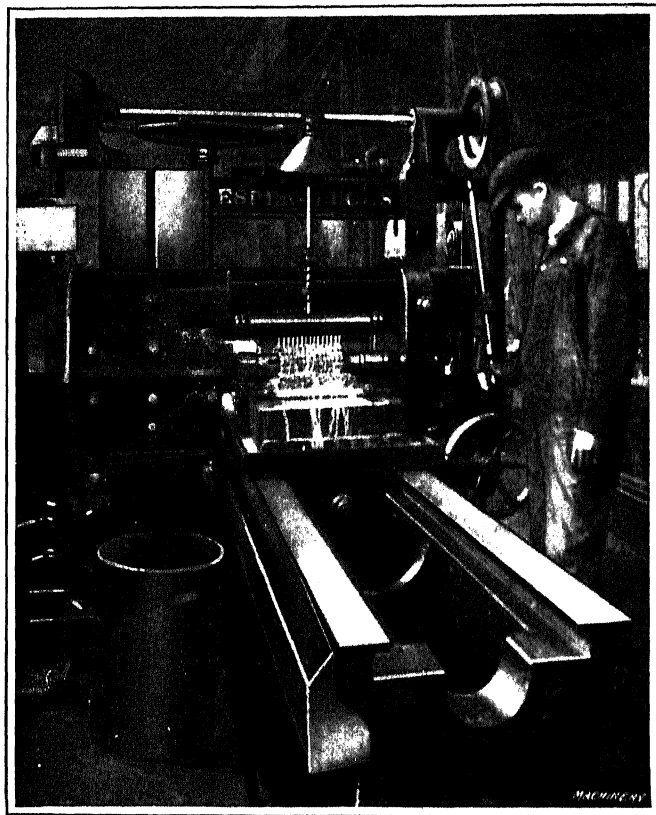


Fig. 14. Means of distributing Coolant on Espen-Lucas Planer Type Milling Machine

taken to prevent this practice. Mr. Taylor was the first to find that the most satisfactory results were obtained by delivering a large volume of water at low pressure to exactly the required position, because water delivered in this way will cover a large area and will not tend to rebound from the work, thus exerting its maximum effect as a coolant.

The direction in which the fluid is applied should always be selected with the view of obtaining a location where it will remain on the work long enough to have the maximum effect, that is to say, where there will not be a great tendency to throw the coolant; and this is particularly desirable in

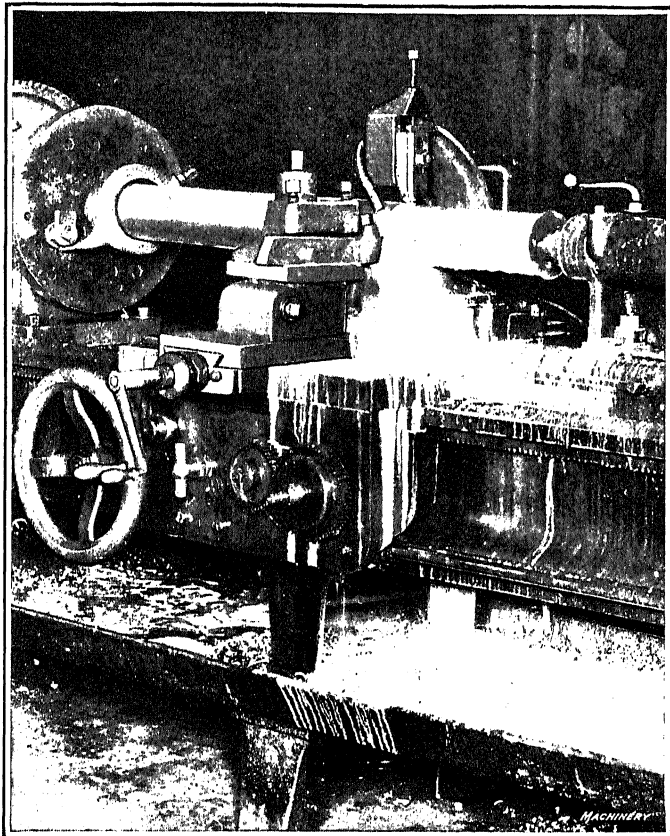


Fig. 15. Provision for delivering Copious Flow of Compound to insure Adequate Cooling of Tools and Work

the case of high-speed machinery such as grinding machines, because the fluid may actually be thrown clear of the work, on the operator and the floor surrounding the machine. In this connection the pressure at which the fluid is applied is also very important; if the pressure is too high there will be

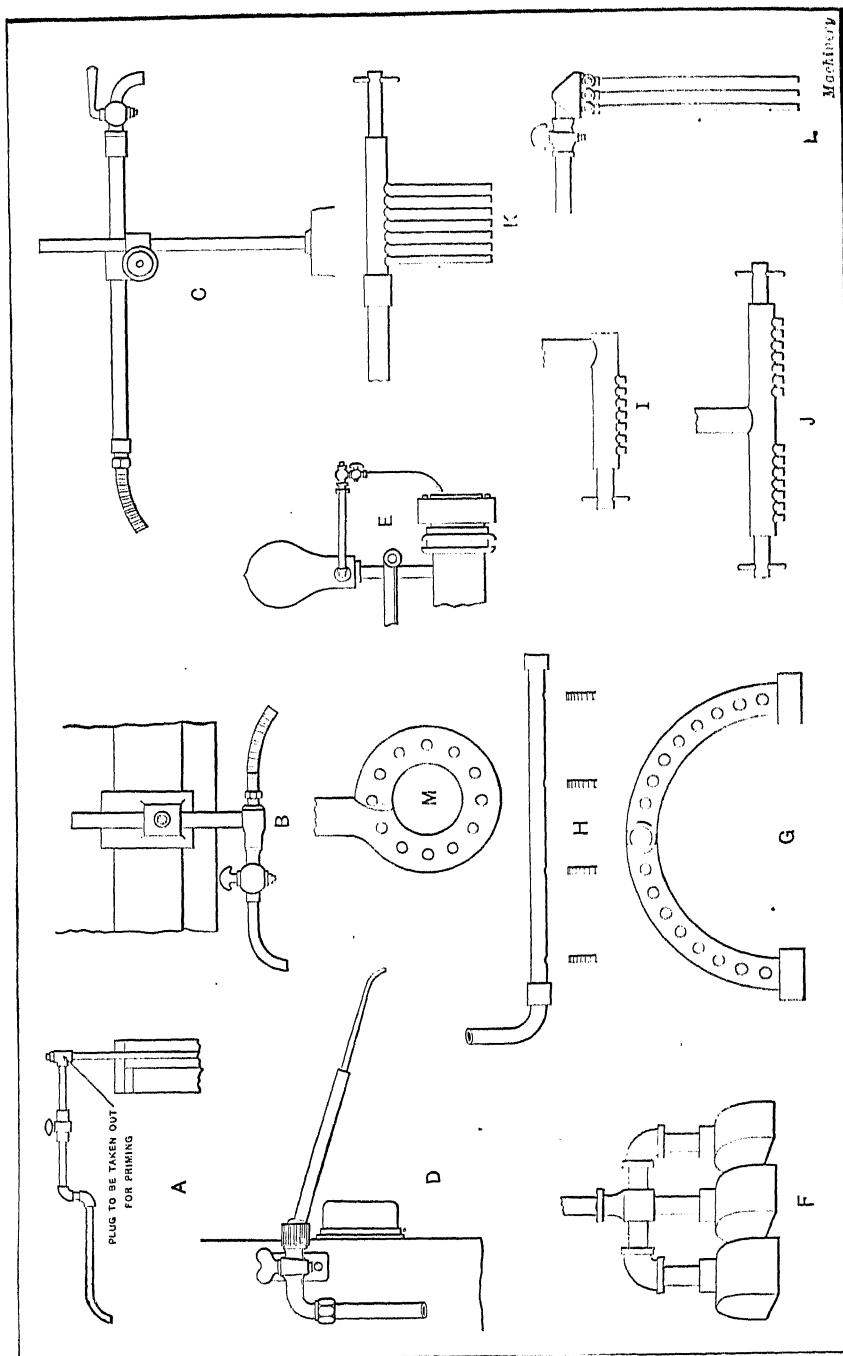


Fig. 16. Miscellaneous Examples of Nozzles and Delivery Tubes for supplying Coolant to Tools

a tendency for the fluid to rebound upon striking the work, so that it will not have the maximum effect in cooling and lubricating. If, on the other hand, the pressure is low, the fluid is enabled to remain on the work, thus absorbing heat and cooling the bearing between the chip and lip of the tool. The best practice calls for the delivery of a large volume of fluid at low pressure, and as oils and cutting compounds are now being purified so that they can be used continuously, this use of a large volume of even high-priced oil involves only a moderate increase in investment in oil upon which the overhead charge is not likely to be excessive.

Forms of Nozzles and Distributing Devices. In delivering coolant to the tools it is obviously important to apply it at exactly the points where cooling and lubrication are required, and for this purpose many different forms of delivery tubes and nozzles are employed. Typical examples of such devices are illustrated in Figs. 16 and 17. For single-point cutting tools, narrow milling cutters, drills, etc., a pipe with a single outlet is all that is necessary, but two or more outlets are required for gangs of cutters and multiple tools unless a wide spout is used. The simplest arrangement available is a plain pipe with an open end. In most cases, however, it is necessary to provide adjustment for locating the nozzle in the desired position relative to the work. At *A* it will be seen that the pipe is hinged to provide for swinging the nozzle into place over the work. Another good example of this kind is illustrated at *B*, which consists of a small faucet supported by a rod clamped in such a way that both vertical and horizontal adjustment are obtained. Connection between the faucet and supply pipe is made by a flexible tube. A similar example is shown at *C* in which the faucet is supported by a clamp carried by a rod screwed into a tapped hole in a machine boss or similar member. The delivery pipe shown at *D* is provided with what might properly be called universal adjustment, as the first section of pipe has a ball and socket joint which enables it to be swung in practically any direction, while the second section of pipe slides in and out to give the desired length. An arrangement for delivering coolant to a bolt threading die

is shown at *E*, where it will be seen that the vertical nozzle may be swung around the horizontal delivery pipe to obtain the desired radial position, and this nozzle is bent to direct the flow of cutting compound into the die. The supply is delivered by a plunger pump and the air bell provides for absorbing the effect of pulsations and obtaining a uniform pressure.

In heavy milling operations, flooding of the cutters is highly important. In milling, the chips are usually short, so friction between the cutter teeth and chips is not likely to be very great. In such cases the fluid acts as a coolant rather than a lubricant; and to keep the fluid on the work use is made of shields at the end of the delivery pipe which drop down over the cutters in such a way that any fluid which is thrown up is caught by these shields and drops back on the tool and work. An example of this form of delivery pipe and shield is shown at *F*. In another section of this treatise reference will be made to the use of compressed air for cooling work and tools. In order to distribute the air over the cutter so that it may exert the maximum cooling action, the delivery pipe is constructed as shown at *G*. At each side of the cutter there is a pipe bent to the same curvature as the cutter. A series of holes is drilled in the pipe corresponding to the spacing of the cutter teeth so that air flows on the tool and prevents the steel from becoming over heated. Another device for delivering fluid to milling cutters is shown at *H*, which consists of a horizontal pipe with holes drilled in it to correspond to locations of a gang of four milling cutters. Such an arrangement proves satisfactory provided the pipe and holes are of ample size to deliver the required volume of fluid.

For delivering coolant to multiple turning tools such as those used on the Fitchburg "Lo-swing" lathe, and similar cases where it is required to obtain considerable distribution of the fluid, delivery tubes of the form shown at *I*, *J* and *K* may be advantageously employed. It will be seen that these consist of horizontal pipes to which delivery nozzles are connected, and the spacing and length of these nozzles may be varied according to the requirements. In handling different

classes of work, there will be different numbers of tools in use, and in order to adapt these delivery pipes to the requirements of various cases, sliding plugs are provided in one or both ends, which may be moved to shut off the supply of coolant to those nozzles which are not required. A somewhat similar arrangement is shown at *L* except that in this case the delivery tubes are pivoted in order that the adjustment of each tube may be regulated according to the position in which it is required to apply the cutting compound. At *M* is shown a good method of delivering coolant to drills, end-mills and similar tools that are doing heavy work. The ring pipe surrounds the tool and delivers the fluid in a practically continuous circle, through holes which are inclined inward toward the tool.

A device is shown at *N*, Fig. 17, which was developed for use in delivering fluid to hacksaw blades and other similar tools. It will be seen that this consists of a pipe with a cap at one end and a valve at the other which provides for turning on or off the entire supply of fluid. Holes drilled along the pipe allow the coolant to escape to a sheet-metal plate *a* over which it flows to the saw and work. This device was especially developed for delivering cutting compound to hacksaw blades and is placed in such a position that plate *a* comes up against the side of the blade, thus distributing the coolant uniformly.

At *O* is shown a method of delivering oil or cutting compound to several tools. This will be seen to consist of an inner tube connected to the supply pipe with an outer tube which is a sliding fit over it. The bearing between the inner and outer tubes is a close fit in order to be leak-proof. Drilled in both tubes is a series of unequally spaced holes located in such a way that when the outer tube is slid along, different numbers of holes in the inner and outer tubes will come into coincidence in order to allow for the escape of oil or cutting compound at these points. For instance, in the position shown there are three openings, but if the outer tube were moved to the right through a distance equal to one space between holes, it would result in providing four openings. Pipes of this kind may be made with different spacing

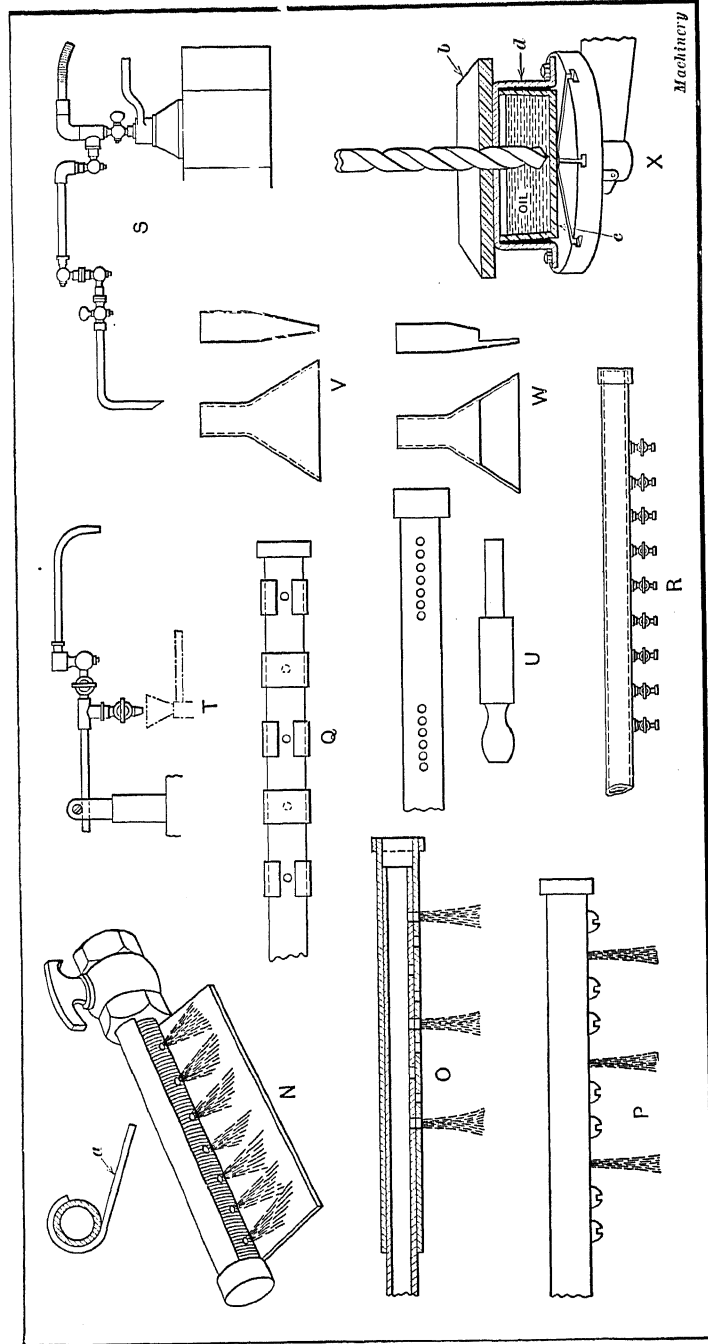


Fig. 17. Other Examples of Nozzles and Delivery Tubes for Oils and Compounds

of holes for delivering oil or compound to different combinations of tools.

The delivery pipe shown at *P* is adapted for supplying cutting compound to multiple tools, and is a substitute for the one shown at *O*. In the present case it will be seen that a single capped pipe is used in which a series of holes has been drilled and tapped. Screws are furnished to plug up these holes and the necessary number of screws can be removed in those positions where it is required to deliver cutting compound to the tools. Still another method of securing the same result is shown at *Q*; in this case holes are also drilled in the pipe, but spring clips made of sheet steel surround the pipe, and by twisting the clips around so that the opening between the ends of the clip exposes the necessary number of holes the cutting compound can be delivered to a number of tools.

At *R* is shown a somewhat similar idea for the cooling of gangs of tools and for use in cases where it is desired to deliver coolant over a considerable area. A delivery tube of this form would be used for supplying fluid to multiple turning tools and similar cases. It will be seen that each outlet is provided with a small cock which can be turned on and off according to the positions at which it is desired to deliver fluid. At *S* and *T* are shown two methods of delivering oils or compounds to tools on screw machines and turret lathes. The method shown at *S* will be seen to consist of a double supply pipe, one branch leading to the center of the turret for carrying coolant directly to the points of oil-tube tools, and the other delivering coolant to other kinds of tools held in the turret. A somewhat similar arrangement is shown at *T*, where it will be seen that the first branch of the pipe delivers oil into a funnel which communicates with the center of the turret to supply oil-tube tools, while a branch pipe carries oil to forming tools, etc.

In handling automatic screw machine work where there are a number of tools working at the same time, the problem of delivering oil is somewhat more difficult, as it is required to supply the proper amount of oil to all tools and still prevent delivering it at intermediate points where no

tools are in operation. The latter consideration makes it impractical to use a pipe with a long orifice which extends across the full length of the piece on which the tools are working. A typical example is shown at *U*, and this also illustrates a satisfactory device. Suppose we have a piece of work of the form shown on which the small diameter is being turned down by a box-tool, while a forming tool is at work on the left-hand end of the piece. It is required to deliver oil to both the box-tool and forming tool, but if oil is also delivered on the intermediate diameter on which no work is being done it will result in a reduction of the supply of oil available at those points where it is required. A simple and efficient method of overcoming the difficulty is to have a horizontal pipe with holes drilled in it through which oil can flow on the forming tool and box-tool, but with no holes drilled in the intermediate space where the bar is not being machined. This idea is capable of extension to cover a great variety of cases.

In delivering coolant to a milling cutter of considerable width or to a hob it is necessary to distribute the fluid over the entire width of the tool, and in cases of this kind use may be made of the forms of nozzles shown at *V* and *W*, both of which provide for distributing the fluid over a considerable area. It will be seen that nozzle *V* is of the so-called "closed" type and this is used in a vertical position; nozzle *W* is open at one side and is usually employed where the delivery pipe comes to the cutter in a horizontal or slightly inclined position. Where desired, both of these types of nozzles may be supported on a clamp and the end of the regular delivery pipe dropped into them in order to avoid changing the standard form of pipe, which is required on the machine for handling many classes of work.

Probably there is no device for delivering coolant to cutting tools which is capable of more general application than the well known flexible metallic tube that may be connected to the delivery pipe on the machine and bent to deliver cutting compound to the tools and work in exactly the desired position and direction. Tubes of this kind are made in different standard lengths so that they may be coupled to the

machines, and they make a very convenient method for applying lubricant to drills, lathe tools, etc., where the fluid is not required to be distributed over a wide area; such tubes also may be used to advantage for connecting the machine supply pipe with different forms of nozzles, examples of this kind being shown at *B* and *C*, Fig. 16.

At *X* is shown a method of cooling twist drills used for drilling thin metal plates *b* on a drill press not provided with means for circulating the coolant. When this job was first turned over to the machine operator he was instructed to lubricate the drill from time to time with oil from a squirt can, but this method proved slow and tedious, and the operator devised the substitute shown in this illustration. It will be seen to consist of a shallow pan *c* filled with oil and a support *d* over this pan which holds work *b* ready for drilling. Support *d* has a hole drilled in it, and after passing through the work the tip of the drill dips into the oil before its travel is stopped. In this way the drill is provided with a supply of lubricant each time it completes cutting one hole and none of the operator's time is taken up in applying oil with a brush or squirt can.

Methods of Delivering Coolants to Grinding Wheels. Various forms of nozzles and distributors are used for delivering coolants to grinding wheels and work that is being ground. A number of devices for this purpose are illustrated in Figs. 18 and 19. At *A* is shown one of the simplest methods of delivering coolant to a grinding wheel; it will be seen that this consists of a pipe *a* arranged to throw the fluid tangentially against the wheel at the point where it is in contact with the work. A shut-off cock *b* provides for stopping the flow of coolant when so desired. This device is used on the car wheel grinder made by the Norton Grinding Co. of Worcester, Mass., and is applicable for other classes of cylindrical grinding. In this case no attempt has been made to provide fine adjustment of the way in which the fluid strikes the wheel, and for machines working on those classes of grinding where such adjustment is necessary special devices must be provided. At *B* is shown a supply pipe and distributor used on cylindrical grinding machines built by the

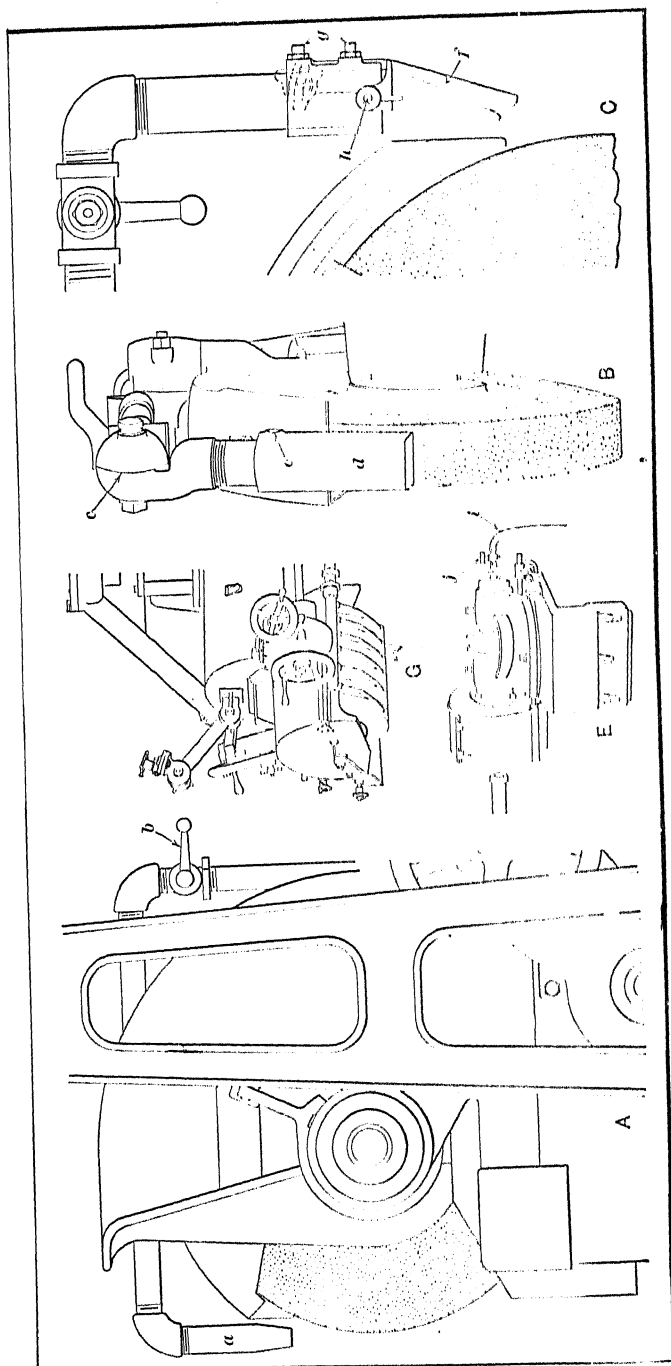


Fig. 18. Miscellaneous Examples of Distributors for delivering Coolants to Grinding Wheels

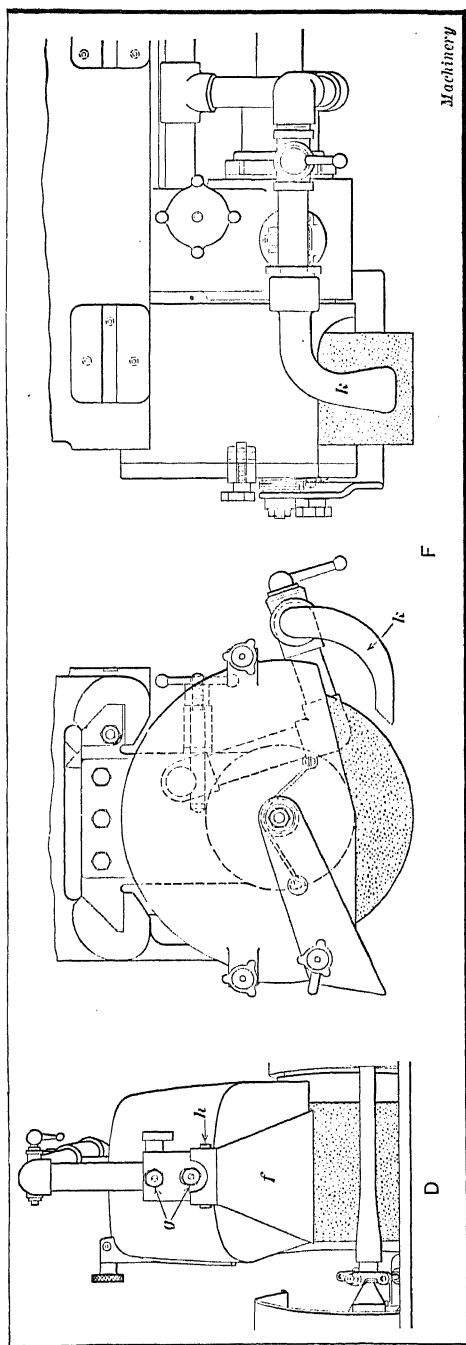


Fig. 19. Additional examples of Distributors for Delivering Coolants to Grinding Wheels

Landis Tool Co. of Waynesboro, Pa. Here it will be seen that the pipe is jointed at *c* so that the angle and position at which the fluid strikes the wheel may be adjusted. At the end of the pipe there is a distributor *d*, the position of which may be regulated vertically on the pipe by loosening screw *e*. At *C* and *D* are shown two forms of distributor *f* may be adjusted vertically on the pipe by

loosening screws *g*, and the distributor swings about a pivot *h* that enables it to be set at any desired angle. It will be evident that in the case of the nozzles shown at *B*, *C* and *D* a shut-off cock is provided to enable the flow to be stopped when so desired. Adjustment of distributor *f* governs the supply of water, the force with which it strikes the wheel and work, and the form that it takes after leaving the spout. The distributor is locked in place by the knob at the right-hand side.

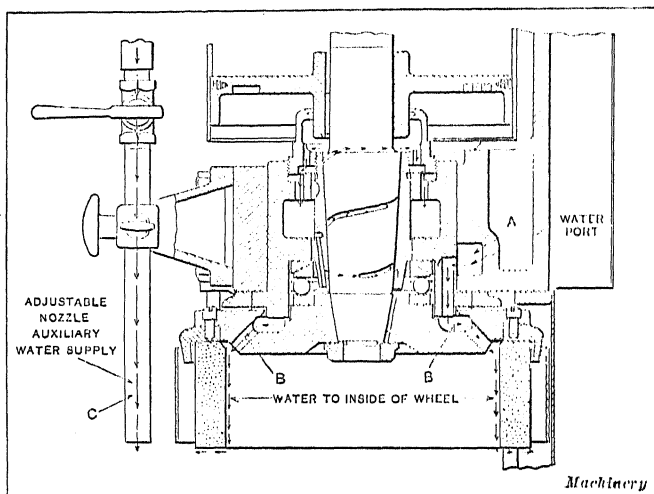


Fig. 20. Means provided for delivering Coolant to Surface Grinder

For internal grinding it is the practice to deliver coolant to wheel and work through the hollow work-spindle, and at *E* are shown the means provided for this purpose on the internal grinding machines built by the Heald Machine Co. of Worcester, Mass. Coolant is carried to the hollow work-spindle through pipe *i*, and a cock *j* enables water to be turned on or off as required. On internal grinding, particularly on small work, it is highly important to provide for delivering the required volume of coolant at low pressure, because if the fluid were delivered under any appreciable pressure, it would be thrown out from the work with considerable violence. In grinding gasoline engine cylinders and

similar work, the cooling action is provided in a different way; instead of delivering coolant direct to the wheel, water is circulated through the water jacket of the cylinder casting, which keeps the temperature of the work low enough so that it will not be burned. At *F* is shown the method by which coolant is delivered to Norton surface grinders. Here it will be seen that a pipe *k* delivers the fluid to the wheel, and the position of this pipe may be readily adjusted to regulate the angle at which the fluid is delivered. A special application of such delivery pipes for use on a surface grinder where there are six wheels is shown at *G*. Here it will be seen that there are six nozzles leading from one manifold to provide for supplying each grinding wheel with the required volume of coolant.

On Blanchard surface grinders the work is carried on a rotating table which runs in the opposite direction to the cup-wheel, and in this case the method of delivering coolant to the wheel and work is provided in the design of the machine, as shown in Fig. 20. From the pump a 1-inch pipe runs to the wheel-head, where it connects with a cored passage *A*, from which water passes down into the annular recess *B* in the faceplate and thence outward and downward inside the grinding wheel. The water in passing through the inclined holes in the faceplate is whirled at the full speed of the wheel, and issues from under the cutting face with considerable force, so that it thoroughly cleans the wheel face in addition to affording the required cooling action. An auxiliary adjustable pipe *C* is provided to deliver a heavy stream of water directly over the work-table. Both inside and outside pipes have independent valves. A generous supply of fluid is particularly desirable in grinding dies and other hardened work where overheating would be very detrimental.

Designing Tools to provide for Cooling. In designing cutting tools it is sometimes possible to make provision for the delivery of oils or compounds which will be the means of producing more satisfactory results than would otherwise be the case. An example of this kind is shown at *A*, Fig. 21, which consists of an inserted-tooth milling cutter used

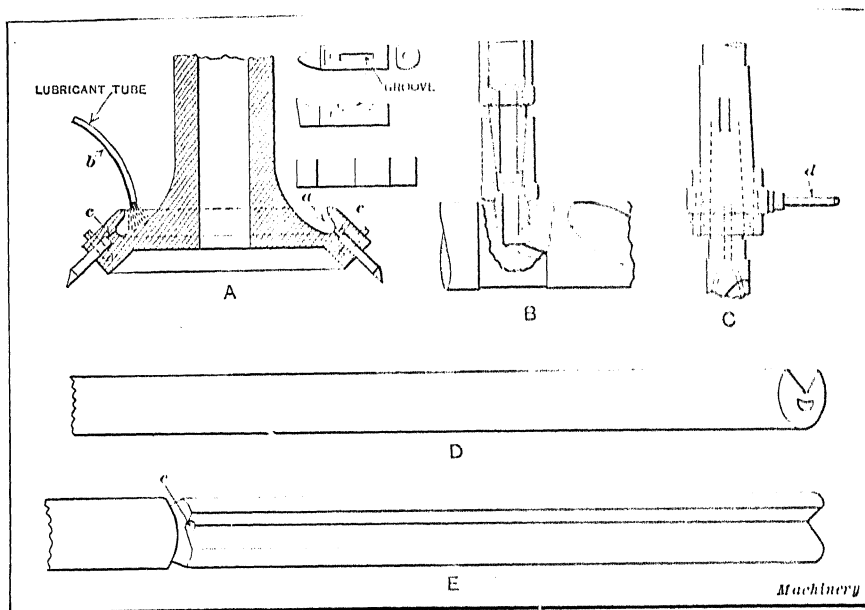


Fig. 21. Methods of delivering Coolant to Oil-tube Tools—Drill and Reamer for Deep Holes

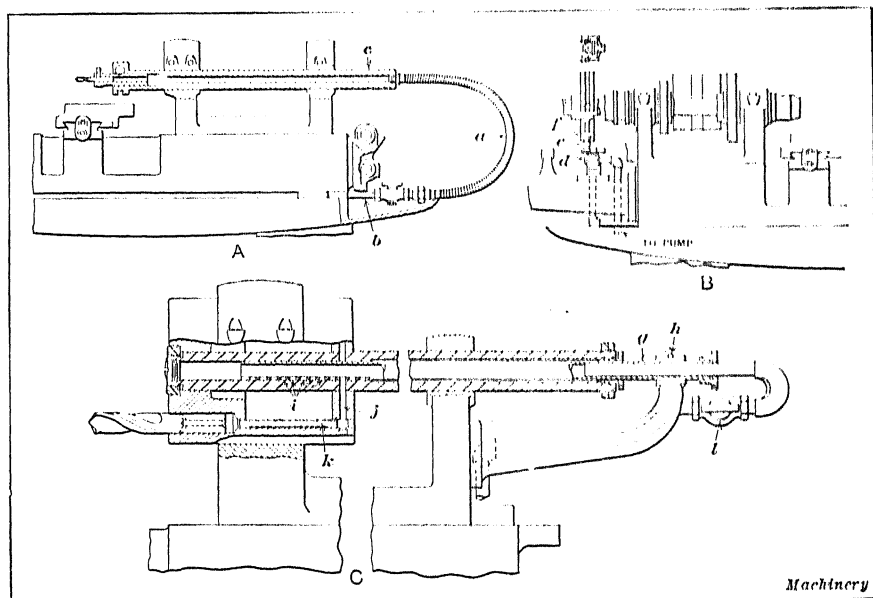


Fig. 22. Examples from Practice in delivering Coolant to Oil-tube Tools

on a vertical milling machine. It will be seen that a groove *a* is provided around the head of this cutter into which coolant is delivered by pipe *b*. From this groove holes *c* connect with each of the inserted-tooth cutters, and these, in turn, have a hole drilled at the upper end and a groove cut in the side to allow coolant to reach the point of the tool. In this way the fluid goes right to the cutting point, where it is most necessary.

At *B* and *C* are shown two typical methods of making connection with oil-tube drills and similar tools. At *B* the tool remains stationary and the work revolves, so that it is possible to deliver oil through a tube threaded into the side of the drill. At *C* the drill revolves while the work remains stationary, and in this case a collar which is a sliding fit on the drill makes connection with the oil-tubes in the drill, oil being delivered through small pipe *d* to an annular space in the collar. For deep-hole drilling and similar work the action of the oil in washing chips out of the hole is very important, and in order to be effective the oil should be delivered at high pressure. An extreme case in deep-hole drilling is seen in drilling rifle barrels, this work being done by a tool of the form shown at *D*. It is of the oil-tube type, the drill point being made of steel and brazed to the end of a steel tube. This tube is rolled in such a way that a groove is formed down one side; oil is delivered through the center of the tube and through oil-tubes in the drill point, and returns by way of the outside groove through which the chips are washed out. As the oil is delivered at a pressure of about 800 pounds per square inch, care must be taken to prevent it from splashing, and for this purpose a guard is furnished which surrounds the end of the work to catch the oil and chips and divert them into the pan of the machine. A deep-hole reamer of the oil-tube type is illustrated at *E* in Fig. 21. In this reamer, oil for cooling the tool and washing away chips is delivered through hole *e*.

Machine Design as Applied to Tool Lubrication. The forms of distributing tubes and nozzles shown in Figs. 16 and 17 may be connected to the delivery pipe on practically

any form of machine, and do not involve alteration of the original design in any way. But there are many cases where it is necessary to work out the design of machine members in order to provide for delivering coolant to cutting tools, and typical examples of this kind are shown in Fig. 22. A simple device for use in connection with oil-tube tools is shown at *A*. It consists of a flexible tube *a* attached to the oil pipe *b* leading from pump. The flexible tube is attached to the back end of tailstock spindle *c* and the oil flows through the hollow tailstock spindle to the tool. This device is used on automatic screw machines built by the Cleveland Automatic Machine Co., Cleveland, Ohio. This firm also uses an automatic shut-off device, shown at *B*, which consists of an oil cock *d* having a special four-pointed star on its stem, which is turned to shut off or open the oil cock by adjustable pins *e* mounted on cam drum *f*. This is an extra attachment which is supplied with the oil feed when required, but the device shown at *A* meets all requirements in most cases, allowing the oil to feed through the cutting tool continuously.

At *C* is shown a device, which is also used on machines made by the Cleveland Automatic Machine Co., that provides for delivering oil to each turret hole, so that oil-tube drills, reamers, boring tools, counterbores, etc., may be placed in any or all turret holes as required. The valve mechanism which controls the flow of oil to different turret holes permits its flow only to the tool which is actually cutting, and automatically shuts off the oil from all the other holes. Starting and stopping the flow of oil is accomplished by forward and backward movement of the turret shaft. Oil-tube *g*, which extends inside the turret shaft, is equipped with a valve that controls the flow of oil, this tube being adjustable longitudinally and clamped in any position by screw *h* in the oil-feed bracket. At the forward end of tube *g* there is a series of holes *i* arranged in a single row at the lower part of the tube and extending over a length equal to the turret stroke. Oil-tube *g* is held stationary at all times, and when the turret shaft moves forward and backward on its regular stroke, hole *j* in the turret

passes over this series of holes in the tube, allowing oil to flow through hole j and tube k to the turret hole and thence through oil-tubes in the tool. Oil is delivered to only the lowest turret hole, which is in line with the spindle of the machine; all other holes in the turret are shut off. The position in which oil-tube g is clamped determines when

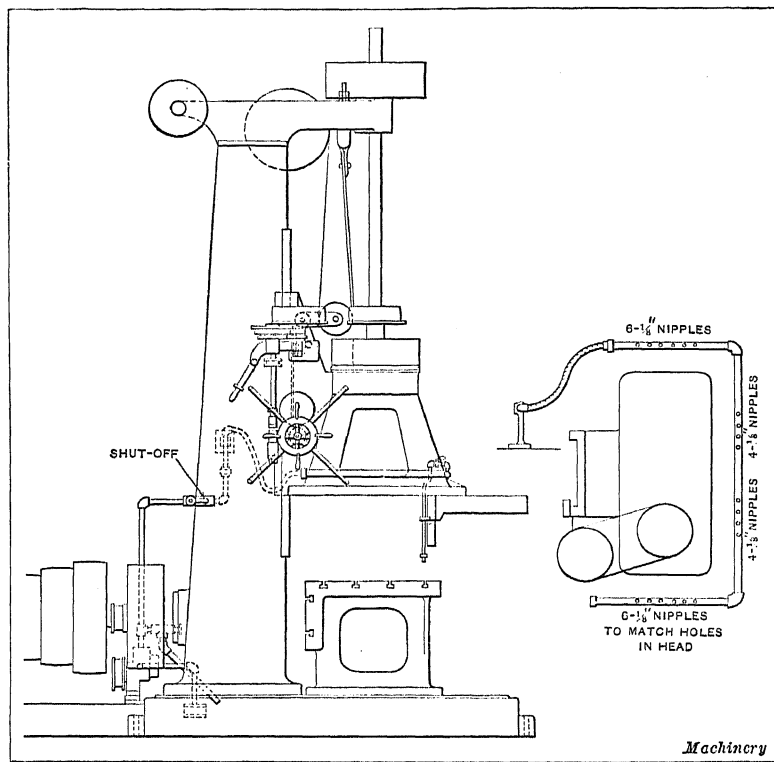


Fig. 23. System of distributing Coolant on Multiple-spindle Drilling Machine

the flow of oil will commence; in other words, it is possible to have the flow of oil through the tool for the full length or any part of the stroke, the idea being that if the work is short, the oil will not start to flow until the tool has reached the work; it is for this reason that adjustment of oil-tube g is provided. The supply of oil may be shut off by closing

valve *l* if so desired, this valve being placed in the main delivery pipe leading from the pump.

Too much emphasis cannot be laid upon the desirability of having machine tool builders provide all the equipment necessary for delivering cutting compound to the tools on the machines which they manufacture. We frequently see machines of otherwise excellent design which the user

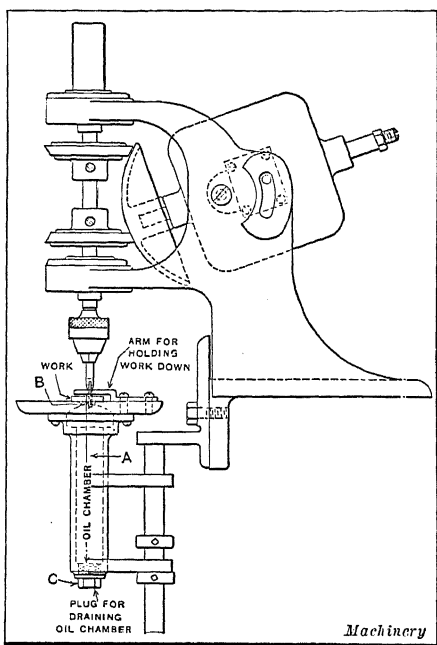


Fig. 24. Provision made for delivering Oil to Tap of a Variable-speed Tapping Machine

has rigged up with makeshifts for the delivery of coolant to the tools. Even under the most favorable conditions it cannot be expected that men in the user's factory, who are specialists in the production end of a business, can design devices for delivering coolant to tools that will be as efficient or look as well as those worked out by designers in the machine tool builder's factory. It has been stated that practice in the cooling of cutting tools is often far below the standard of manufact-

uring efficiency in other branches of the productive system in many factories. The same condition is true of machine design, as the development of means for delivering cutting compound to machines is often far below the average of excellence attained in other branches of design.

The sort of devices with which machine tools should be equipped are illustrated in Figs. 23 and 24. The first of these shows a multiple-spindle drilling machine made by

the Baush Machine Tool Co., Springfield, Mass. It will be seen that there is a flexible tube connecting the head to the piping system to provide for movement of this head. A distributing pipe runs around the lower end of the head with an individual tube connected to each spindle; and each tube has its individual shut-off, so that cutting compound is not delivered to those spindles which are not in use. Also there is a shut-off in the main supply pipe for shutting off the entire flow of coolant, and a relief valve provides for maintaining the desired pressure at which coolant is delivered to the drills.

Fig. 24 shows a device for distributing coolant to small taps, used on a variable-speed tapping machine made by the Anderson Die Machine Co. of Bridgeport, Conn. It will be noticed that the vertical stem that supports the work table is made hollow to provide an oil chamber *A*. In this table there is a small hole *B* through which the tap passes, and the level of oil in chamber *A* is kept up to the top surface of the table. Each time the tap passes through the work it dips into the oil, thus washing off chips and providing the tap with a fresh supply of coolant for the next cut. The chips drop to the bottom of the oil reservoir, and in addition to preventing damage of the thread while the tap is being backed out, tend to keep the level of oil in the reservoir high enough so that the tap will always dip into it. When the reservoir becomes filled with chips, threaded plug *C* is removed so that the reservoir can be washed out with kerosene ready to receive a fresh supply of oil.

CHAPTER IV

COLLECTING USED OILS AND COMPOUNDS AND RECLAIMING OILS FROM CHIPS

IN the discussion of methods of delivering oils and compounds to the tools and work, it was mentioned that one of the simplest means was to provide a drip can from which a small stream of oil or cutting compound is delivered to the tool. Similarly, the simplest means of collecting the fluid for subsequent use is to have a can suspended under the machine, into which the oil drains after running over the tools and work. It is evident that this system is inadequate when the supply of oil or compound required is so great that it becomes necessary to empty the can at frequent intervals.

Methods of Collecting Oil or Cutting Compound. Necessity for cooling tools is now generally recognized, and provision is made on most machine tools for collecting the coolant and pumping it back to the tools. The usual method of collecting fluid is to have an oil trough surrounding the work-table. At *B*, Fig. 1, the rim surrounding the trough is made flush with the table surface to allow overhang of the work and tools. Sometimes the rim surrounding the oil trough extends up above the table level, which is a desirable feature where the work or fixtures do not project beyond the table. Diagram *C* shows an oil trough surrounding a radial drilling machine table where there are both horizontal and vertical surfaces on which to clamp the work. It is important to prevent chips from finding their way into the oil reservoir from which the pump draws its supply, and a simple method of accomplishing this is shown at *D*, where it will be seen that there is a small weir surrounding the outlet. The same purpose is served by the cover plate shown at *E*, which extends over the oil

trough; a screen is sometimes provided at the end of the trough from which oil is drawn off to be returned to the reservoir. A slight modification of the oil trough system is shown at *G*, in which it will be seen that a large reservoir is provided at each end of the table, connected by small oil troughs and also by a pipe through which the oil is drawn off to be returned to the reservoir.

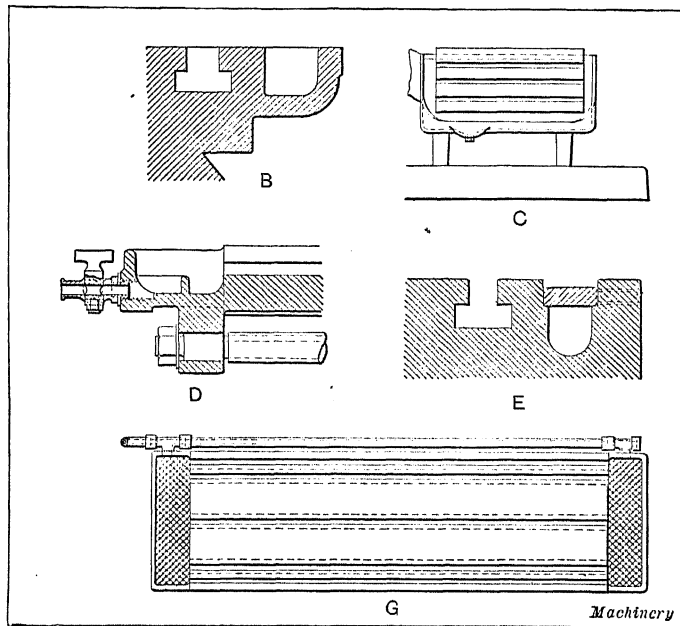


Fig. 1. Examples of Table Trough Design

There are numerous methods of making connection between the oil trough in the table and the reservoir from which oil is pumped back to the work. At *A* and *B* in Fig. 2 are shown two simple methods of collection for use on reciprocating and rotating tables, respectively. Here it will be seen that drain channels on the moving tables are arranged in such a way that they are always located over fixed channels from which connection is made with the reservoir. At *C* is shown the method of draining oil or compound from a rotary milling machine table. When the range of movement is too great to make it possible to apply

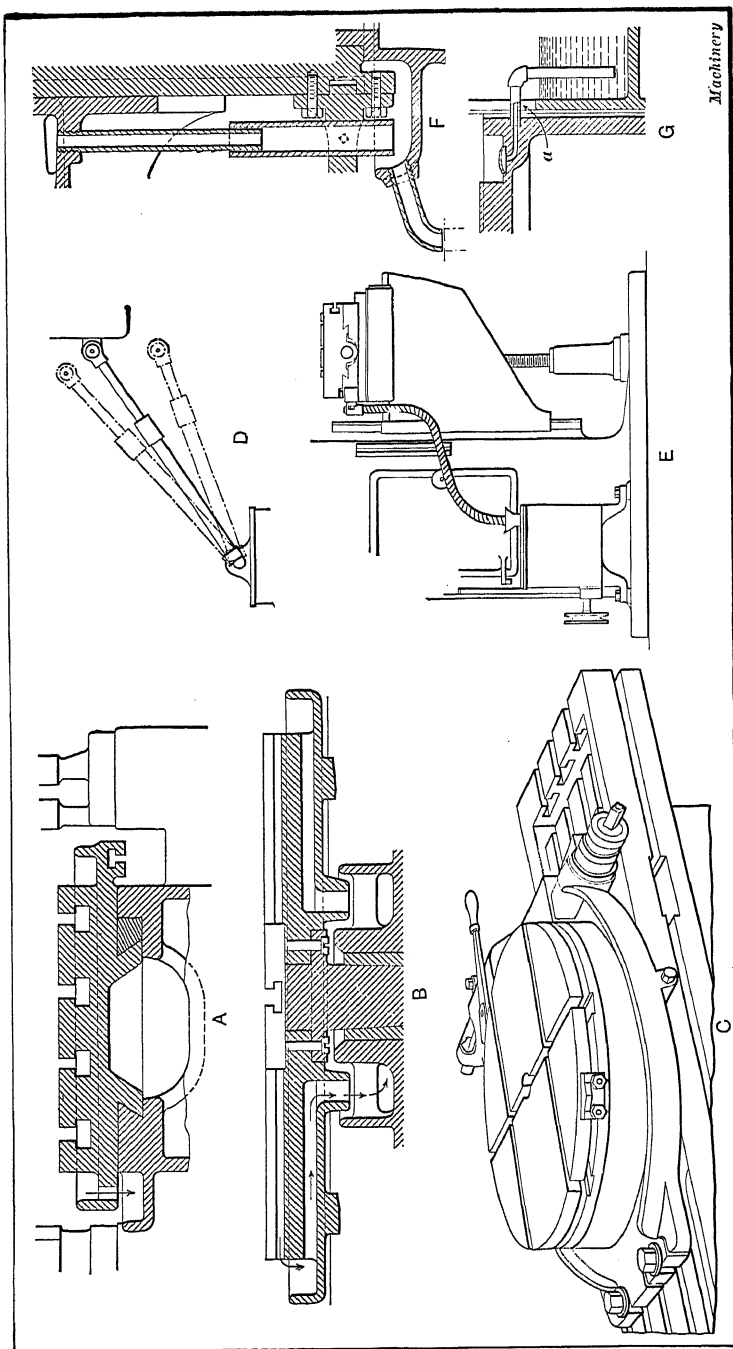


Fig. 2. Methods of making Connection between Trough on Moving Table and Reservoir in Machine from which Coolant is pumped back to Work

the principles of design shown at *A* and *B* or when trouble may be experienced from splashing of the oil or cutting compound, some other form of construction must be applied. In many cases use may be made of telescopic tubes which provide for table movement in both a horizontal and vertical direction, an example of this kind being shown at *D*. In similar cases a flexible tube may be used, as illustrated at *E*, provided the length or position is not such as to inconvenience the machine operator. When it is merely necessary to take care of vertical movement, as in the case

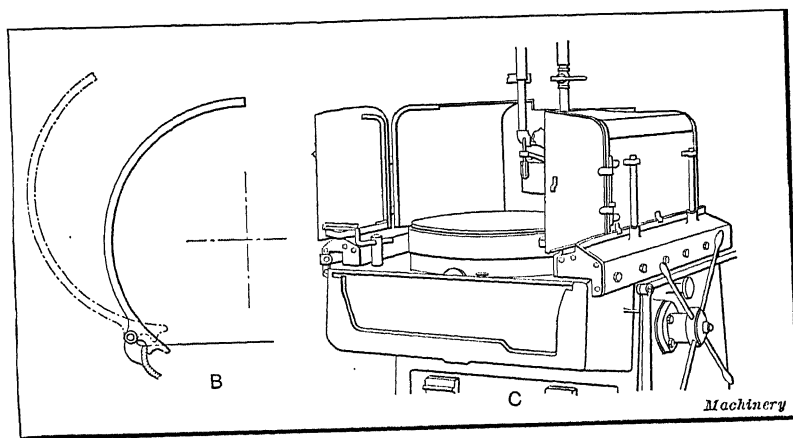


Fig. 3. Examples of Splash Guard Design

of tables on drilling machines, etc., the oil trough surrounding the table may be conveniently drained by a telescopic tube as shown at *F*, or by a tube which slides in a vertical slot *a* as illustrated at *G*.

When trouble is experienced from the throwing of oil or cutting compound from high-speed machinery, splash guards must be provided, common examples of this kind being seen on most grinding machines. One type of splash guard is formed of flat plates secured by clips which enable the guards to be removed for inspection or adjustment of the machine. At *B*, Fig. 3, a curved guard is shown which is hinged, and it is common practice to have two such guards located at each side on grinding machines, automatic

screw machines, etc., so that the moving part is completely enclosed, making it impossible for oil to be thrown on the floor or to soil the operator's clothing. The type of guard shown at *C* is used on grinding machines built by the Blanchard Machine Co., Cambridge, Mass. As the table moves out to remove finished work and reload the chuck, the doors open automatically and they close in the same way when the table moves back under the wheel. This excellent design makes it impossible for spray to be thrown from the wheel and does not delay the operator.

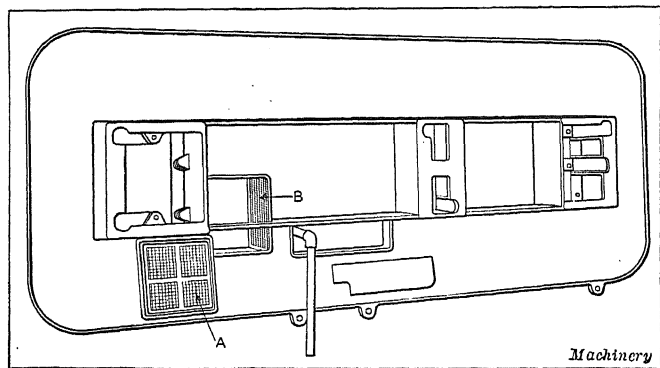


Fig. 4. Oil Pan used on Automatic Screw Machines showing Efficient Strainers to insure Complete Removal of Chips

Arrangement of Oil and Chip Pans. To facilitate catching oil and cutting compound used on machine tools, it is now common practice to provide machine tools with pans which are familiar to all those who are employed in or have occasion to visit machine shops.

In designing oil and chip pans careful attention should be paid to the provision of means for removing all chips and grit from the oil before it is pumped back to the work. This is important for two reasons: First, chips and grit in the oil tend to damage both the pump and bearings of machine tools to which the coolant is delivered; second, dirty oil is less efficient as a lubricant and coolant. Fig. 4 shows a good example of oil and chip pan design used on automatic screw machines made by the Cleveland Auto-

matic Machine Co., Cleveland, Ohio. The strainer *A* is perforated with large holes, allowing the coolant to pass through freely. The screen *B* has small perforations through which the coolant passes more slowly, thus allowing foreign matter to settle to the bottom. The pump suction pipe shown dipping into the well is fitted with another fine strainer. The consequence is that the oil passes through three strainers before reaching the pump and work, which means that it is pretty sure to be free from chips.

In showing examples of different manufacturers' practice in designing various machines, it is not the intention

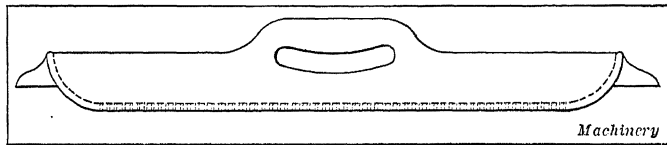


Fig. 5. Perforated Tray for Use inside Oil Pan to facilitate Removal of Chips

to imply that the examples shown are the best; but they have been selected at random to indicate the features of design that should receive careful attention in dealing with the problem of delivering cutting compound to tools. In some cases straining of chips from oil or cutting compound is accomplished by placing a separate strainer in the chip pan or above the reservoir inside the machine. Such strainers should be furnished with handles, as in the case of the one illustrated in Fig. 5, so that they may be easily lifted out. The disadvantage of this practice is that unless particular care is taken a lot of the oil or compound is likely to drip on the floor while dumping the contents of the strainer into a truck, thus tending to create an unsanitary and unsafe condition in the factory.

An alternative system is to use portable oil pans as shown in Fig. 6, which can be run into place under a machine and removed at will. Such pans are used in factories where certain classes of work call for the use of oil or cutting compounds, while other classes of work can be machined

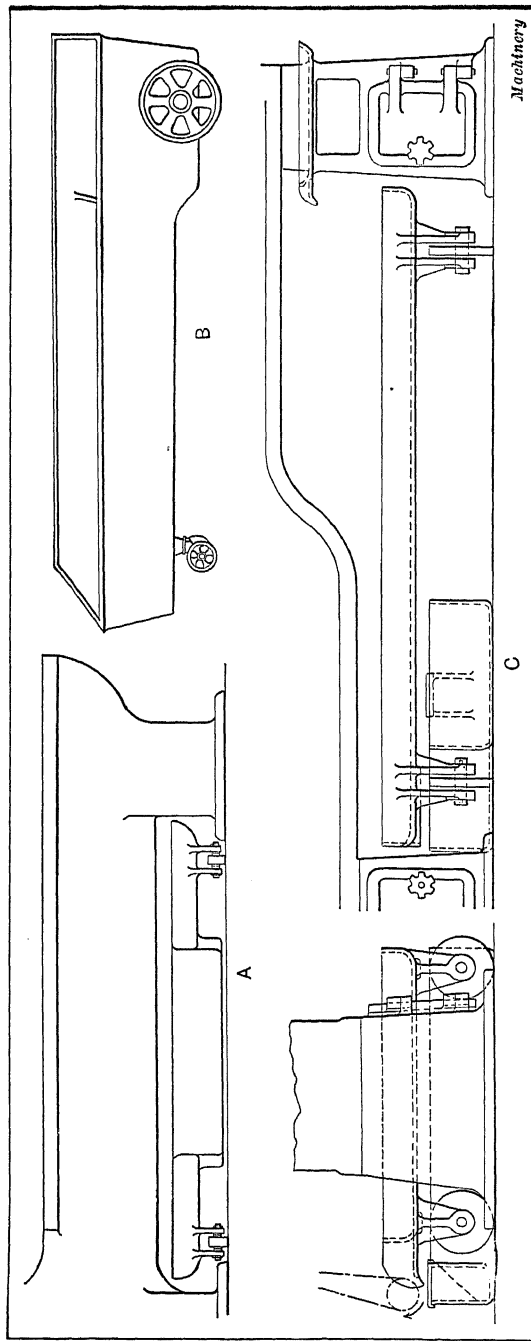


Fig. 6. Portable Oil Pans which can be used to Advantage under Automatic Screw Machines, etc., making Removal of Chips an Easy Matter

dry. In addition, many manufacturers prefer the use of portable pans on automatic screw machines and other tools that produce a large quantity of chips, as the use of such pans facilitates the removal of chips. Automatic screw machines built by the New Britain Machine Co., New Britain, Conn., are furnished with portable pans of the type shown at B, which, it will be seen, is furnished with a strainer and sump into which oil drains ready for pumping back to the machine.

In making rounds with an oil-tight truck, the man employed to remove chips from the machine swings the shallow end of the pan out from under the machine so that he can easily shovel the chips into the truck. The pan is then pushed back, the whole operation taking but a few minutes.

Provision of Pump Reservoirs in Machines. The design of reservoirs in which oil or cutting compound is collected to be pumped back to the work is governed by the class of machine and kind of work to be done. In nearly all cases, strainers or other means provided in oil and chip pans for the removal of chips and coarse dirt from the fluid allow some finely divided material to pass, and provision should be made in the reservoir for the removal of as much of this suspended matter as possible. Common practice is to divide the reservoir into separate compartments by means of baffle plates over which the fluid must flow; and the first compartment into which the fluid comes from the chip pan should be of sufficient size to allow time for suspended matter to settle to the bottom before the fluid reaches the section of the reservoir in which the pump suction pipe is located. In cases where considerable heat is developed by the machining operation, which must be absorbed by the cutting compound, this large reservoir serves another purpose in that it exposes a considerable surface of the fluid and facilitates radiation of heat. In developing oil mixtures and cutting compounds a great deal of thought has been paid to the development of fluids which radiate heat readily. With properly designed reservoirs and fluids of this kind, tests conducted by suspending an accurate thermometer in the reservoir show that the temperature of the fluid does not rise appreciably during an entire working day.

With the evolution of machine design it became evident that in most cases the best location for the oil reservoir is inside the hollow frame casting on milling machines, drill presses, lathes and other machine tools, because this constitutes a space in which coolant can be stored, and the position is such that the reservoir does not take up space that is

not actually required for the machine. Fig. 7 illustrates a sectional view of a drilling machine column with a reservoir provided in this way; and Fig. 8 shows a similar sectional view of a bolt threading machine. In all cases of this kind it is of the utmost importance to provide for the removal of chips, dirt and other foreign matter from the fluid before it reaches the suction chamber from which the

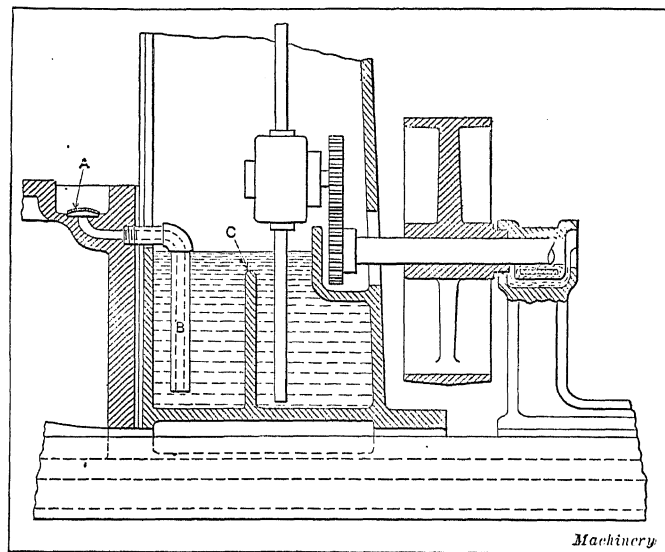


Fig. 7. Sectional View of Frame of Drilling Machine showing Arrangement of Coolant Reservoir

pump delivers it back to the tools and work. In the drilling machine column, Fig. 7, the oil or compound collected in the trough surrounding the table runs through strainer A into drain pipe B, which extends down close to the bottom of the reservoir. Any fine material which gets through the strainer settles by gravity while the fluid runs over baffle plate C into the suction chamber. It will be noticed that the pump used in this case is direct-connected by gearing from the main driving pulley shaft.

In the bolt threader (built by the National Machinery Co.), shown in Fig. 8, the coolant runs back into the reservoir, which is furnished with a strainer A; in this case

the strainer is made separate from the reservoir so that it may be lifted out for removing the chips. The pump suction connects with the lower section in this reservoir, and it will be noticed that an inclined plate *B* is located in such a way that any fine chips which pass through the strainer will settle at the right-hand side of this plate, while the pump suction located to the left is thus assured of obtaining a supply of clean coolant. The pump, which is of the

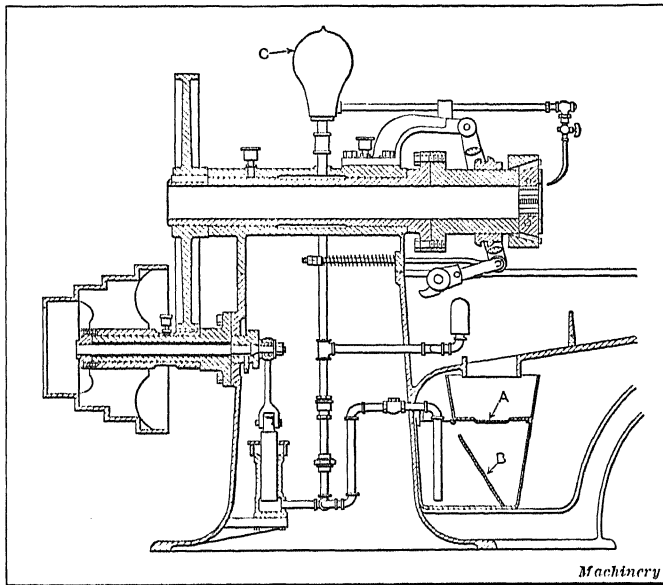


Fig. 8. Sectional View of Bolt Threader showing means of Distributing and purifying Cutting Compound

plunger type, is direct-connected to the driving shaft, and in order to equalize pressure as far as possible an air bell *C* is provided, which cushions variations that would otherwise exist.

Removal of Oil from Chips with Centrifugal Separators. There are many factories in which the management is prone to think that advantage is taken of every method of improving efficiency and reducing manufacturing costs, but in which chips are sent to the foundry that have a lot of oil sticking to them. This is apparent when the chips have

been standing at the scrap pile for a sufficient length of time to allow a considerable amount of oil to drain off. Sometimes the oil becomes rancid, in which case its presence is made evident by the disagreeable odor. In most plants operating automatic screw machines or other tools which produce many chips, centrifugal separators are employed to remove oil before the chips are sent to the foundry to be melted. In the operation of these separators there is another chance for the wasting of oil or compound. If the chips are conveyed from the machines to the separator in a leaky wheelbarrow, there is every opportunity for part of the oil adhering to them to drain out on the floor and be wasted. If workmen could be led to regard each gallon of oil as the equivalent in money, according to the class of oil and market conditions at the time of its purchase, it is certain that all conscientious men would be more careful in handling this material. Oil-tight trucks are available for carrying chips, and investment in one or more trucks of this kind is strongly recommended, both as regards oil economy and the maintenance of sanitary conditions in the shop.

The character of the chips will govern to some extent the efficiency of the separators for removing oil from them. The easiest chips to handle are those which are long and curly, so that the oil is not too closely confined in the mass of chips; conversely, it is most difficult to make a complete extraction of oil from fine chips, and saw swarf is about the most difficult material to handle. The consensus of opinion among manufacturers seems to be that the most complete extraction of oil is obtained with the smaller sizes of centrifugal separators, and probably this is due to the fact that there is not such a large mass of chips in the separator at any one time. On the other hand, the cost of handling chips and oil is greater in the case of small separators, which must be stopped at frequent intervals to recharge. With kerosene, experiments have shown that 140 pounds of chips are capable of holding one gallon of oil, and for oils of higher viscosity the amount held by the chips would be greater. For instance, thirty pounds of

chips will hold about a gallon of mineral lard oil. This is sufficient to emphasize the importance of installing centrifugal separators to remove the oil. In order to obtain a satisfactory degree of efficiency tests should be made at regular intervals to determine the time chips should be left

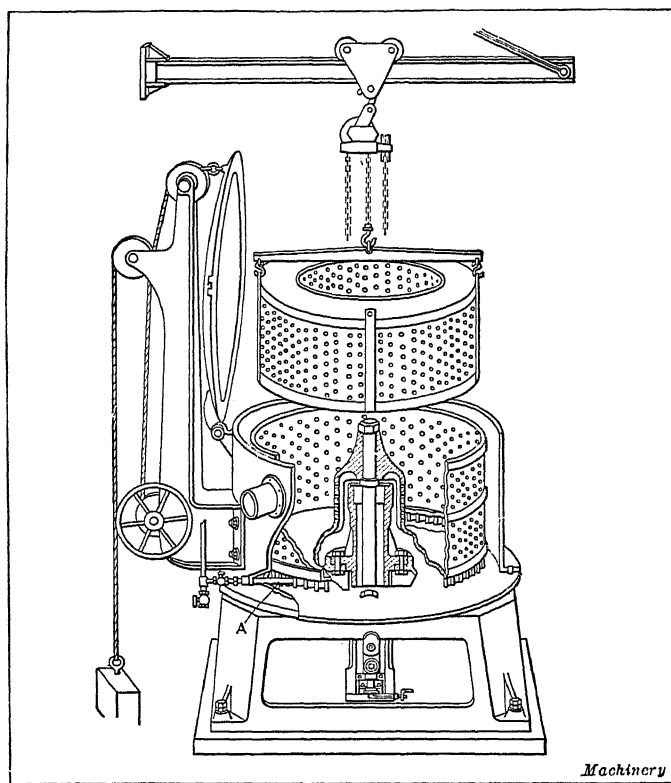


Fig. 9. Turbine-driven Centrifugal Chip Separator

in the separator and the speed to prevent unnecessary loss of oil.

Where a lot of chips are handled it is good practice to pile them on a grid so that the oil may drain through and be collected, thus reducing the time required for centrifugalizing. In some plants conveyors may be used to advantage for carrying chips to the department where oil is

recovered. Settling tanks may be employed in making a preliminary purification of oil before it is filtered, and the centrifugal separator department should be conveniently located for sending chips back to the foundry.

Fig. 9 shows a centrifugal chip separator built by the Oil & Waste Saving Machine Co., Philadelphia, Pa., that is

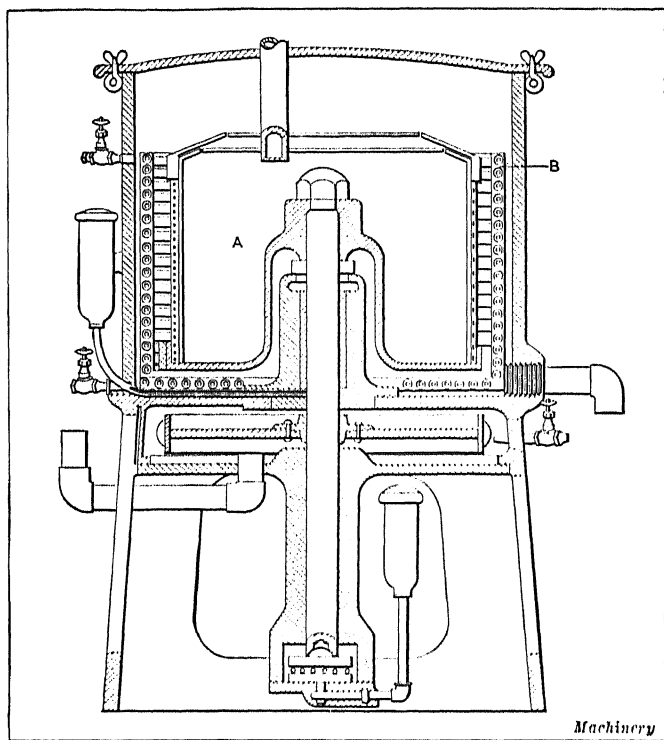


Fig. 10. Turbine-driven Centrifugal Filter and Drier for purifying Oil recovered from Chip Separator

driven by a direct-connected steam turbine. The chips are contained in a rotating basket and the high speed of rotation results in removing the oil by centrifugal force. It will be seen that a special hoist raises the chip basket, making it easy to remove the dry chips and substitute a fresh charge. The nozzle through which steam is delivered to the turbine is shown at A, and after passing the turbine wheel the

steam heats the chips, thus making the oil more fluid and facilitating the action of centrifugal force; it is also claimed that this raising of temperature serves to sterilize the oil. A minimum efficiency of 98 per cent is claimed for the turbine-driven separators. These chip separators are made in two sizes, with baskets which have capacities for holding $3\frac{1}{2}$ and 8 cubic feet of chips, respectively. On the large machine the basket is 36 inches in diameter; the speed of rotation is 600 revolutions per minute; and the time required to remove the oil from a basketful of chips, including charging and removal, is ten minutes.

Condensed steam from the turbine forms an emulsion with the oil, and as this would have a detrimental effect on both tools and machines, it is desirable to remove it before the oil is used again. For this purpose the manufacturers have built a centrifugal oil filter, shown in Fig. 10, which is also driven by a direct-connected turbine. Centrifugal force causes the oil to be driven through a series of filtering mediums composed of sawdust, cloth and paper, which line the chamber *A* in the machine, into which the oil is delivered continuously, thus removing all solid matter. The oil is sprayed upon steam-heated evaporating coils *B* which surround the filtering chamber, and in this way all water is removed and the oil is converted from an emulsion to a pure oil which is suitable for use under the most exacting requirements. This filter is made in two sizes, known as 15- and 20-inch sizes, respectively. In the 15-inch size the basket rotates at 1500 revolutions per minute and the filter has a capacity of purifying from twenty to thirty gallons of oil per hour. In the larger machine the filter runs at 1000 revolutions per minute, and it can purify from fifty to sixty gallons of oil per hour.

CHAPTER V

FILTERING AND STERILIZING SYSTEMS

THE purity of an oil or compound delivered to metal-cutting tools is a most important factor in determining the amount and quality of service that will be obtained from the tools. When great care is not taken, in filtering, to remove such impurities as oxide or scale and particles of metal from the oil, the fluid frequently becomes heavily charged with these impurities and trouble is experienced through rapid wear of bearings and slides of machine tools, rapid destruction of the cutting edge of tools, and inferior finish on the work. The following analysis of machining or "cutting" costs shows what an important effect the purity of oil or cutting compound may have on the cost of production. Cutting costs can be classified under the following heads:

Labor: (1) Operation of machine tools; (2) time occupied in changing dull tools; (3) time occupied in resharpening tools.

Power required to drive machines.

Cost of steel for cutting tools. .

The cost of labor for operating machine tools will naturally vary according to the location of the factory and the skill required for conducting the various machining operations. This labor cost per unit of work produced is naturally cut down by any increase effected in the rate of production, and one important way of obtaining higher production is to increase the life of cutting tools so that delays occasioned by shutting down machines for changing tools is reduced as far as possible. The use of good cutting compounds may be responsible for an increase in production of as much as 35 or 40 per cent.

The time required in changing dull tools will vary according to the complexity of the machine and tools; and in addition to the direct cost, there is an indirect cost through loss of production while the machine and its operator are idle. Even under the best conditions, the cost of resharpening tools is a factor of some importance. As the use of pure oil of suitable quality is the means of increasing the life of cutting tools, it will be evident that this reduces the cost of changing and resharpening tools.

The power required to drive the machines is reduced by increasing the speed at which they are driven, but it is only possible to take advantage of this condition when the cutting tools are kept sharp, which, in turn, requires the use of a suitable coolant kept in good condition through proper filtration. The saving of power effected through the use of good cutting oils and compounds is dealt with in detail later. The cost of steel for cutting tools is directly controlled by the amount of service obtained between grindings, which depends largely on the quality of oil or cutting compound, as previously explained.

Filtration of Oil Recovered by Centrifugal Separators. Fig. 1 shows an apparatus for the purification of oil recovered from centrifugal chip separators, which was designed and built by S. F. Bowser & Co., Inc., Fort Wayne, Ind., for installation in the plant of the Timken Roller Bearing Co., Canton, Ohio. It will be seen that hopper *A* is furnished with chutes for delivering chips into the baskets of separators *B*, the hopper being so arranged that chips may be delivered to it by a container carried on a trolley. The separators are placed on the second floor of the building in order to facilitate shoveling the cleaned chips into a car for shipment. Oil from the separators is carried down into header *C*, which delivers it into heating cylinders *D*, which are connected in series; in each case the pipe leading into the cylinder extends down to a point close to the bottom and the oil flows up through the cylinder and out by way of a pipe near the top. Each cylinder is furnished with a steam coil, so that the temperature of the oil is raised to about 170 degrees F. It will be noted that a by-pass is provided to

allow one or both of the cylinders to be cut out of the system if necessary.

The heated oil next flows through tanks *E*, *F*, and *G*, which are connected in series, the oil being delivered into each tank through a pipe extending down almost to the apex of

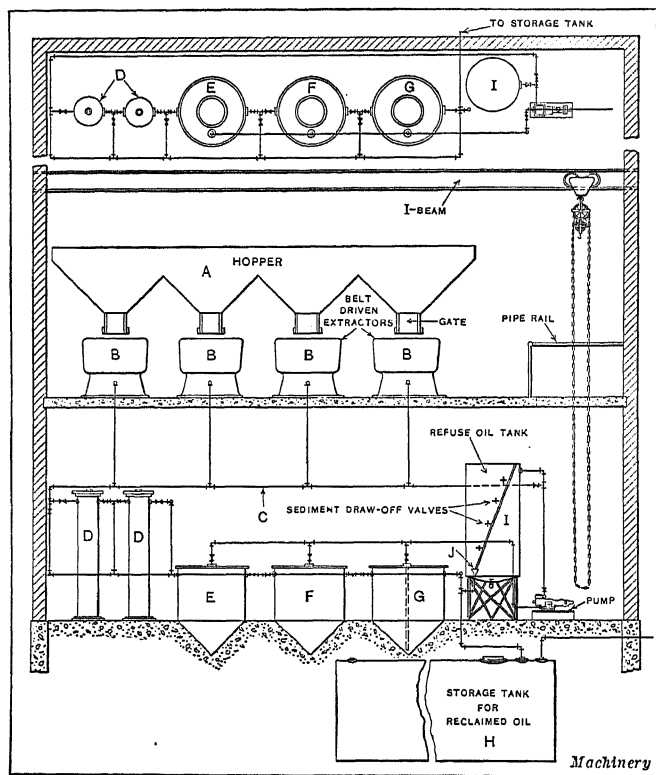


Fig. 1. Apparatus for purifying Oil recovered from Centrifugal Separators

the conical bottom and escaping through a pipe near the top of the tank. Tanks *E* and *F* provide for the settling out of chips and other foreign matter held in suspension in the oil, while tank *G* is furnished with a steam coil to provide for raising the temperature of the oil to 200 degrees F. in order to sterilize it. The rate of flow is so adjusted that the oil is held in tank *G* for fifteen minutes, which is regarded

as sufficient time to effect complete sterilization. Clean oil from the tanks flows into storage tank *H*, from which it is pumped back to the machines. Refuse oil from the conical bottoms of tanks *E*, *F* and *G* is pumped into tank *I*, in which it is allowed to stand for a sufficient length of time to allow impurities to settle to the bottom. It is then possible to draw off the better grade of oil through cocks which deliver it into funnel *J* carried on a pipe connection to the header leading to storage tank *H*. About 75 per cent of the oil recovered from tank *I* is suitable for use on metal-cutting tools, and the remainder of the oil is used on machinery which is of such a character that a poor grade of oil can be employed with satisfactory results.

Practice of Nash Motors Co. in Purifying Cutting Oil. There is an interesting equipment, used by the Nash Motors Co., Kenosha, Wis., for the purification of oil recovered by the use of centrifugal chip separators. The oil from the chip separators passes into a settling tank in which coarse dirt and chips are precipitated. From the settling tank the oil runs by gravity through a pipe into a storage tank, from which it is pumped into four settling tanks. These tanks are provided with steam coils, which raise the temperature of the oil to about 240 degrees F., at which it is held for one hour, after which the oil is allowed to stand for from twelve to twenty-four hours to allow all impurities to settle to the bottom.

The centrifugal chip separators are driven by steam turbines, which pass exhaust steam into the chip baskets to facilitate the separation of oil, and in so doing the oil becomes mixed with water that must be removed before it is returned to the machine tools. This is done by passing the oil into a battery of three centrifugal cream separators, from which the pure oil is collected in steel barrels. These barrels are carried through the shop on trucks and the oil is pumped into tanks on the machines by means of hand pumps on the barrels.

Oil carried away by chips and recovered through the use of centrifugal separators usually contains many impurities such as particles of iron oxide, fine chips, etc., which makes

careful filtration a matter of great importance. In place of the methods of filtration that have been described in the foregoing, some manufacturers have found that it is better practice to use horizontal filter presses for cleaning oil recovered by centrifugal chip separators. In these presses the fluid to be purified is passed through a series of porous diaphragms, supported in a horizontal frame; and to increase the rate of filtration, pressure is applied to the fluid by a plunger operated by a capstan wheel and screw or other suitable means. Experience has shown that if finely ground Fuller's earth, kieselguhr, or similar mineral matter is added, this material will build up on the diaphragms of the filter and form a porous structure that constitutes a highly efficient filtering medium. Oil purified in this way is often superior in quality to the original oil shipped from the refining plant.

Importance of Filtering Oil or Cutting Compound. Where it is not the practice to filter the oil or cutting compound used on machine tools, impurities carried in suspension by the oil are likely to cause trouble in a number of ways. One of the commonest of these is the damage done to machine-tool slides and bearings through particles of oxide scale and small metal chips. In some cases these impurities exert a harmful effect upon the finish produced by the tools. They also cause trouble through scoring the cylinders of pumps used for circulating oil on individual machines or for distributing it from a central station to all the machines in the factory.

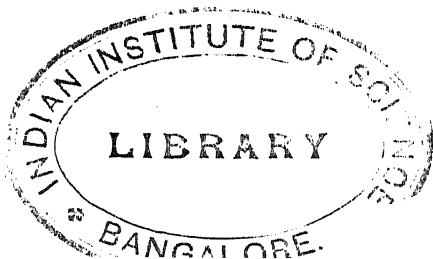
Particles of metal suspended in the oil delivered to cutting tools will sometimes cause the most unexpected difficulties, of which the following is a typical example. In a certain shop it was the practice to manufacture a brass product on automatic screw machines, and when the demand for these brass parts had been temporarily filled, the machines were switched over for operation on a product made from steel bars. In the latter case high-speed steel cutting tools were used. When changing over the machines, all chips were removed from the pans, but the same cutting oil was used on both steel and brass products; and

the oil recovered from either the brass or steel chips sent to the centrifugal separator was returned to the reservoirs in the automatic screw machines.

Occasionally it was found that the high-speed steel tools that had formerly been giving satisfactory service in producing the steel product would suddenly commence to tear the metal and produce an unsatisfactory finish. A careful investigation showed that this trouble was caused by small particles of brass carried by the oil, which had been used on the tools for machining the brass product. These particles of brass tended to pack on the cutting edge of the high-speed tools, and the high temperature of these tools resulted in partly fusing the brass, with the result that it eventually covered the cutting edge and made the tool dull. To the naked eye nothing was visible, but when examined under a strong magnifying glass the accumulation of brass on the tools was seen to be very pronounced. After an effective filtering system was installed these particles of brass were removed from the oil and no further trouble of this kind was experienced.

Central Distributing Station for Oils and Cutting Compounds. The importance of delivering clean oil to metal-cutting tools has long been recognized, but recently the development of means for oil purification has been carried further than was possible with the form of strainers and distributing equipment furnished on individual machine tools. Many large manufacturing plants are now being furnished with central distributing stations from which cutting oils and compounds are delivered to all machines in the factory by a permanent pipe system, and similar systems of drain pipes carry the oil or compound back to the central station where it is purified for subsequent use.

The Richardson-Phenix Co. of Milwaukee, Wis., specializes in the construction of systems for the distribution of oil or cutting compound from a central station to all the machines in the factory, the collecting and returning of this oil to the central station and its purification. This company's system of purification provides for passing the oil through a series of apparatus for the removal of foreign



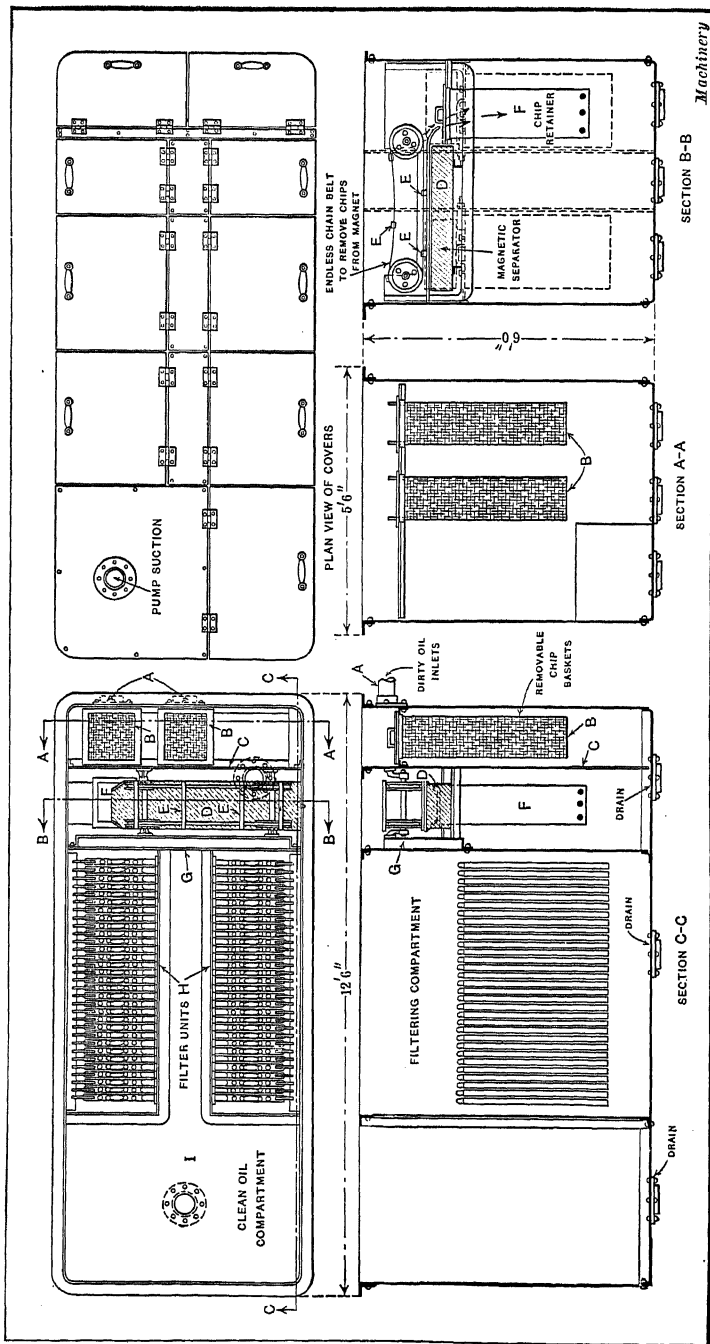


Fig. 2. Filter and Purifier, showing Arrangement of Chip Baskets, Baffle Plates, Magnetic Separator and Filtering Units

matter carried by the oil; in all cases the equipment is built to meet the special requirements of the plant in which it is to be used, and the means provided for purifying the oil will naturally vary in different cases. Fig. 2 shows one of the more complete equipments, from which a good idea may be obtained of the way in which the Richardson-Phenix system is applied. Used oil enters inlets *A* and passes down through strainer baskets *B*, which remove the coarse chips and other impurities. The fluid then flows under baffle plate *C* and up across the top of magnetic separator *D*, where the iron or steel chips are removed. Scrapers *E*, operated by an endless chain belt, travel across the face of this magnet and scrape off the chips into retainer *F*, which is provided with screened holes in the bottom to allow the oil to drain out. Reference to the cross-sectional view on the line *B-B* will show that this chip retainer can be slid to the right and lifted from the tank to empty the chips. After passing over the magnetic separator *D*, the oil flows across dam *G* into the filtering compartment, from which it passes through cloth-covered filtering units *H*, where the most finely divided particles of foreign matter are removed; the clean oil is collected in compartment *I*, from which it is drawn off through the pump suction pipe.

It will be noticed that a large number of filtering units *H* are employed in the system shown in Fig. 2, and the number of these units determines the filtering capacity. As it is possible to provide tanks with the desired number of units, the system is readily adapted to the capacity requirement of the factory in which it is to be used. Fig. 3 shows detail views of one of these filtering units and also the means provided for cleaning it. It consists of a cage covered with galvanized wire mesh over which a cloth bag is tightly stretched so that it is free from folds, which retard filtration. Oil passes into these filtering units from the outside and clean oil escapes through discharge pipe *A*. These discharge pipes fit into automatic valves, and when it is required to remove a unit from the tank it is merely necessary to take hold of handle *B* and slide the unit to the

right, withdrawing discharge pipe *A* from the valve, which then closes automatically. In many cases the only cleaning required is to brush off any dirt which has collected on the cloth. When it is desired to substitute a fresh bag on the unit, thumb-nuts *C* are removed and the top of the filtering unit is lifted off, as shown; this releases the top edge of the cloth bag, which may be drawn down. The edges of the filtering units are made perfectly smooth so the bags will slide easily over them. An important advantage of having

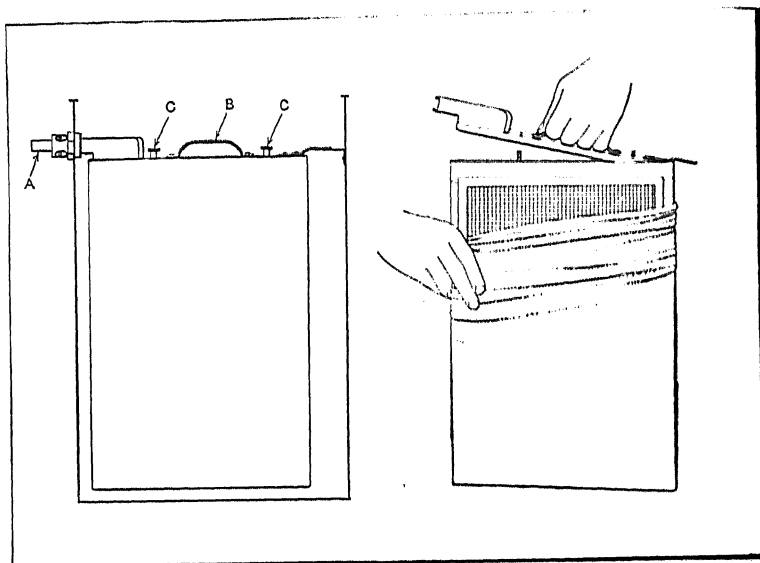


Fig. 3. Close View of Filtering Unit, showing Method of removing Cloth Bag

the filtering units held in a vertical position, with the oil passing from the outside to the inside, is that slime and sediment held by the cloth tend to drop off and settle at the bottom of the tank.

Bowser System of Oil Purification. In the systems built by S. F. Bowser & Co., Inc., for the filtration and sterilization of oils and cutting compounds used on machine tools, the principles employed are somewhat different from those that have already been described. In the type of equipment generally used, dirty oil returned from machines is first

run into large settling tanks, where its temperature is raised by heat supplied from steam coils. This serves to make the oil more fluid and facilitates the settling out of impurities; in addition, the temperature may be raised sufficiently to provide for sterilizing the oil before it is passed on through the filtering units. In all cases the systems are designed and built to meet existing requirements in the factory, but there are certain established principles on which all of these operate.

The dirty oil passes through strainer boxes in which most of the coarse dirt is removed. A cross-sectional view of one of these strainer boxes is shown in Fig. 4, and it will be well to explain how this operates. The oil to be purified enters the strainer box at *C*, and passes down through a chip basket *D*, which collects the larger chips and coarse dirt that have passed through the strainers in the machine-tool oil pans. At the center of the chip basket will be seen twenty-one disks *E*, which consist of iron frames covered with 1/16-inch wire mesh. It will be apparent from the illustration that these disks are so arranged that oil which enters the strainer box passes through the wire mesh into channels *F* leading to a central duct *G*. The purpose of the multiple disk construction is to provide a maximum straining surface so that oil may be passed through the box as rapidly as possible. From duct *G* the oil passes on to subsequent parts of the system through which it passes during the process of purification. In order to clean one of these boxes, the cover is removed to enable the set of disks and the chip basket to be lifted out. It will be seen that the disks are clamped together by a central rod, and that a shield is provided at the front of opening *C* to prevent excessive pressure from driving dirt through the filtering screen at this point. Connection *G* leads from the lower end of the central duct in the strainer boxes through which oil is discharged into magnetic separating tanks. The design of the tanks to be described is quite different from the settling tanks commonly used in Bowser oil reclaiming systems. Instead of being furnished with steam coils for heating the oil to facilitate sedimentation, these tanks are pro-

vided with electromagnets mounted in the cast-iron bases, which cause the chips to be quickly drawn to the bottom of the tanks. As a result, the oil can be handled in this system much more rapidly than where it is necessary to

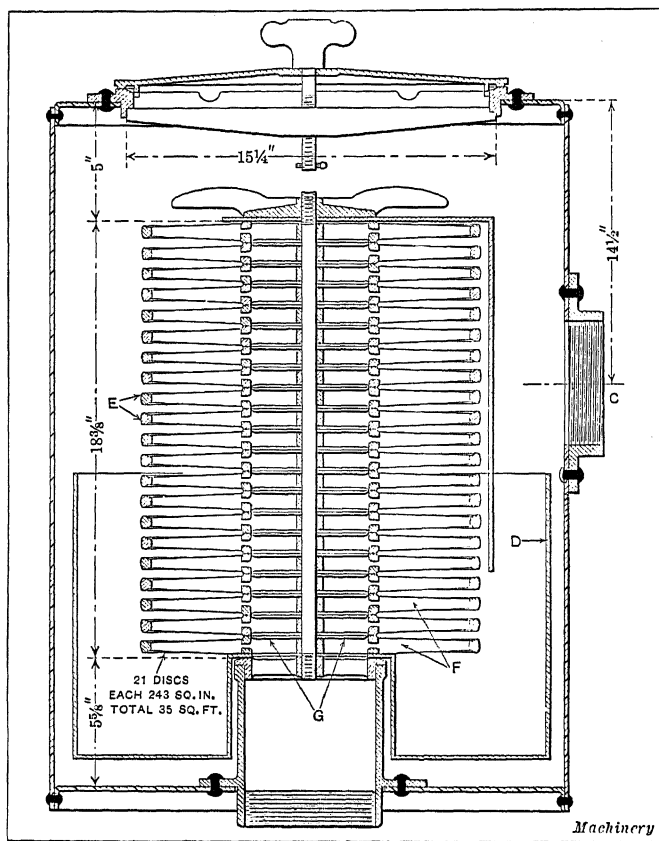


Fig. 4. Detail of Strainer Box used in Oil Reclaiming System

wait for impurities to settle to the bottom of the tanks. Unless special provision were made for overcoming trouble from chips becoming magnetized and sticking to the bottom of the tanks, it would be exceedingly difficult to clean out the accumulation of chips. This is provided for by making the bottom of the tanks of brass, which is non-magnetic, so that when the current is turned off from the

electromagnet, the chips may be easily raked out through two clean-out doors in each tank.

From magnetic separating tanks, the oil passes through pipes into a header which is connected with a battery of four filter tanks. The Bowser filters consist of cloth sleeves held by clamps at top and bottom to metal frames. The only outlet is through the cloth sleeve of the filter units and in flowing through this cloth, fine particles of metal and other foreign matter carried by the oil are removed. The filter sleeves can be removed from the metal frames and washed when necessary. The clean oil passes finally to a storage tank, from which it is pumped back to the machines.

Use of Heat to Facilitate Sedimentation. As previously mentioned, a practice is often made of running the dirty oil into settling tanks in which the temperature of the oil is raised by steam coils in order to facilitate the settling out of impurities held in suspension, and also to provide for sterilizing the oil. A good arrangement of such a system is as follows: The oil is pumped from a storage tank to the machine tools. Drain pipes from chip pans on the machines carry the used oil to return pipes, which deliver it back to the settling tanks and thence to the storage tank. Centrifugal separators are used to recover oil from chips.

The first step in purifying the oil consists of passing it through two heaters. These are merely vertical cylinders connected in series. The oil is delivered at the bottom of the first cylinder and flows up over the steam coil and thence into the second cylinder, where it passes over another steam coil, the temperature of the oil being raised in this way to about 170 degrees F. From the heaters the oil is delivered into four tanks, which are connected in series by pipes that carry the oil down into each tank to a point close to the conical bottom and allow it to escape into the next tank through a pipe placed close to the top. This affords the most favorable condition for allowing impurities in the oil to settle to the bottom of the tank. Two of the tanks are settling tanks, that is to say, their function is to allow the bulk of chips and other suspended impurities to settle out

from the heated oil. The other two tanks are sterilizing tanks and are arranged with steam coils that provide for raising the temperature of the oil to about 200 degrees F. The rate at which the oil flows through the tanks is so adjusted that it takes about thirty minutes for it to flow through all four tanks. From the last sterilizing tank the oil is carried down into the storage tank, from which it can be withdrawn for subsequent use.

Oil that collects in the conical bottoms of the settling tanks is of poor quality, owing to the fact that it contains practically all of the suspended matter originally carried by the entire volume of oil passed through these tanks. This oil requires further treatment before it is fit to be delivered to the cutting tools.

Purification of Soluble Oil Compounds. The purification of emulsions made by the mixture of so-called "soluble" oils with water does not generally require as careful attention as the more viscous oils used on cutting tools when both lubricating and cooling are necessary. This is due to several causes, among which is the fact that emulsions are more fluid than oils and so do not tend to hold such a large quantity of chips and particles of scale in suspension. Another important consideration which simplifies the purification of cutting emulsions is that they are usually employed on those classes of work where it is merely necessary to cool the tools and, as no lubricating action is necessary, the presence of fine chips and dirt is not a serious detriment. Because of these considerations, a much more simple equipment is often employed for the purification of emulsions.

Improvement in Efficiency through Filtration. Any manufacturer who contemplates the installation of equipment for filtering oil or cutting compound will naturally ask the question, "How will the use of such an outfit be valuable in handling my work?" This can best be answered by citing one or two typical experiences of manufacturers who have found that trouble from rapid tool wear or poor finish is due to suspended impurities carried by the oil or compound and who have overcome such difficulties through the installation of an efficient system of filtration.

In the plant of the Boss Nut Co., Chicago, Ill., dissatisfaction was felt with the method of cooling dies and cutting tools. This plant has an equipment of six punch presses of from two to five tons each, and one twenty-ton press; also six nut tappers, having six spindles each. The plant manufactures square and hexagon nuts which are stamped out of 5/16- to 1/2-inch metal.

The former method of cooling was by means of a gravity tank on each press, the coolant being fed through a 1/4-inch pipe to the die, from which it dripped off into a pan underneath the press. The stampings from the presses fell into iron pails with perforated bottoms, so that the coolant would drip off from the finished product. These pails, after standing in the pans for a certain period, were lifted out, the drippings remaining in the pans. In lifting out the pails, a certain amount of cutting compound adhered to the bottom, etc., and later dripped on the floor around each machine. While this loss of cutting compound was not great, in dollars and cents, the task of keeping the floors clean, so that the men could do their work properly, took the time of one or two men about two hours each day; besides, it required two or three men to lift the pails filled with punchings from the presses.

Small rotary pumps were used to deliver the used coolant from the drip pans to the gravity tank; and as the fluid was used over and over again without treatment, it always contained a great deal of scale and other foreign matter. Besides, at the speed at which the machines worked, a considerable portion of the cutting compound at each machine was lost by drippage and by adhering to the finished product. It required the time of two men at least two hours each day to mix and deliver new cutting compound to the various machines; and when this lubricant became so dirty as to render it unfit for use, it was thrown away. In adding or renewing the cutting compound, the time of the operator and the machine itself was also lost, with the result the machines were operating at a low efficiency. By the installation of a Richardson-Phenix filtering system, all these faults were overcome, and the output was increased

upward of 20 per cent. This system was installed in the following manner:

Trenches were cut in the floor, under the presses, of sufficient size and pitch so that the cutting compound would drip from the machine into these trenches, which are connected by a pipe line to a centrally located cutting oil filter. The trenches are covered with grating of $\frac{1}{8}$ - by $\frac{3}{8}$ -inch flat iron spaced $\frac{1}{4}$ inch apart. These gratings are removable, so that they can be easily cleaned and the kegs into which the finished product drops stand on top of the gratings, so that all the drippings flow back to the filter. One of these kegs can be easily and quickly slipped out from under a press and another one inserted. This permits handling the finished product as it comes from the presses, and as one man is now able to do this work, it saves the labor of two men.

Another advantage is that the men operating the presses do not have to stop their machines to fill the gravity tank, nor do they have to pay any attention to whether the pipe leading from the oil tank is full of dirt and grease, but can concentrate all their attention on production. This is also true to the nut-tapping machines. Under the old system it often happened that the operator actually had to wait for compound to be mixed or carried to his machine. The advantage of using a clean compound on drills and taps is self-evident, and while data are not available to show exactly how much longer a tap will last when properly cooled, this company is quite certain that it is getting longer service from the same taps than it ever got before.

Keeping Compound Thoroughly Mixed. Cutting compound is a mechanical mixture and not a chemical compound; therefore, rapid circulation through a central system tends to keep the compound thoroughly mixed. For this reason, this system was so designed that all the compound in the system is circulated ten times per hour, *i. e.*, the system contains 300 gallons of cutting compound, and there is circulated in the various machines 3000 gallons per hour. Hooded drains from the machines should not be used, because if the oil in the compound tends to separate and

float on top it will adhere to the hood, and only the water will be returned to the filter. It was found that a large amount of compound discharging into the drain lines acts as an air-rejector, which fills the drain lines with air pockets and holds back the flow; therefore all air traps should be carefully avoided and the drain line into the filter should be located below the top level of the compound in the filtering compartment. On this class of work there is considerable advantage in using long sweep fittings or bends.

Advantages from Installation of Cooling System. The advantages which this company secured from the installation of a cutting oil system are as follows: The record for the month of December, before the new system was installed, was 4,200,000 nuts. After the system was installed, production for the month of January was 5,300,000 nuts, or an increase in production of 25 per cent; in February 5,500,000 nuts were produced. This increase was made with the same tools and machines and the same number of men. The non-productive work of cleaning up, etc., was eliminated, and the men who formerly did this worked on production.

In another plant where the item of tool up-keep was heavy, it was found that the tools lasted from 33 to 250 per cent longer when supplied with filtered oil or compound. In still another plant, the drills had a tendency to become slightly tapered and wedge in the hole; this was found to be caused by the use of dirty cutting compound, and the trouble was eliminated when the fluid was filtered. With such tools as self-opening dies, this factory found that sediment in the cutting compound sometimes clogged the mechanism so that it was impossible to operate it.

Sterilizing Methods. It has been the experience of manufacturers using large numbers of screw machines and other machine tools on which a lot of cutting oil is required, that the operators of these machines are likely to be troubled from sores on their hands and arms. This trouble has become serious in some shops where case of infection of small cuts and scratches have resulted in employees losing considerable time and, in some cases, in the amputation of hands

or arms. The introduction of employers' liability laws has stimulated investigation of this subject, and it is now believed that these cases of infection are due to the presence of disease-producing bacteria in the oil. To overcome trouble from this source various methods of sterilization have been developed. Chief among these are sterilization by heat and by introducing a germicide into the oil or cutting compound. There is a wide diversity of opinion in regard to the development of bacteria in oils or cutting compounds and the possibility of securing valuable results by sterilization. This fact is indicated by the contradictory results obtained by different investigators, to which reference will be made.

Sterilization by Heat. When the oil or cutting compound is sterilized by heat, the practice is to have a smaller tank connected with the storage tank into which the oil can be pumped. This tank is usually provided with a coil through which steam may be passed to heat the oil, and after this has been done the steam is shut off and cold water passed through the oil to reduce its temperature to that at which it should be returned to the work to give the best results.

Oil mixtures containing cottonseed oil and other vegetable oils become rancid after being in use for some time, which is due to the development of certain molds and bacterial growths. Investigations conducted up to the present, however, tend to show that these are not of disease-producing types and so should not be the cause of infection.

Sterilization by the Addition of Germicide. The sterilization of cutting oils and compounds is still in the process of development, and some manufacturers are now experimenting with the use of carbolic acid, formaldehyde, creosote oils, and other germicides. Small quantities of such chemicals are added to the oil. Such additions have an important advantage over sterilization by heat in that they are circulated through the pump, pipe line, machines, and back to the storage tank, thus having an opportunity of keeping the entire system in a sterile condition. In one well-known manufacturing plant it is the practice to add one ounce of creosote oil to each twenty-five gallons of cutting compound used in the factory. Similarly, a well-known firm of oil

refiners recommends the addition of 2 per cent of carbolic acid to oils or cutting compounds. Carbolic is a weak acid, so far as its action on metals is concerned, and this addition would not result in damaging the machine bearings or the finished work; this acid is also one of the strongest germicides known to science, and such an addition ought to prove helpful in freeing oils and cutting compounds from bacteria.

Fig. 5 shows, in diagrammatical form, the arrangement of a complete Richardson-Phenix oil filter and sterilizer. Dirty oil from the machines enters the system through a pipe (not shown) connecting with the left-hand side of the filter as seen in the diagram. The oil then passes through the series of chip baskets, baffle plates, magnetic separators, and cloth filters. It then passes to pump *B*, which delivers the clean oil to the machines in the factory. It will be seen that the main pipe line is provided with a pressure relief valve at *C*, so that the pressure at which oil is delivered to the tools will not exceed that which has been found most effective. This is an important point, because experience has shown that in order to work at maximum efficiency either an oil or cutting compound should be delivered at exactly the pressure that will enable it to remain in contact with the work instead of having a tendency to rebound. The fluid which escapes through pressure relief valve *C* is returned through a by-pass pipe to the suction chamber of the pump.

Sterilization of oil at a temperature of 140 degrees F. is recommended once every ten days, and when this treatment is necessary, all the oil in the piping and machine pans is allowed to drain down into the filter tank and sterilizer. Oil is pumped through valve *D* into sterilizer *E*, which, it will be seen, is connected with a double pipe line at both top and bottom to provide for passing either steam or cold water through the coil in the sterilizer. After having passed through the sterilizer the oil is carried through a by-pass pipe that carries it back to the filter tank and thence through the filter units back to the sterilizer. This circulation of oil is continued until all the oil in the system has reached a temperature of 140 degrees F.; the oil is kept at this temperature for twenty minutes. Incidentally, repeated

passing of the oil through the filter also gives it a thorough cleaning. While the oil is being heated, both valves *F* are opened to permit steam to pass through the coil in the sterilizer, and after this has been done, these valves are closed and both valves *G* are opened to allow cold water to flow through the coil, thus cooling the oil for subsequent use. Circulation of the oil through the filter and sterilizer is continued while it is being cooled.

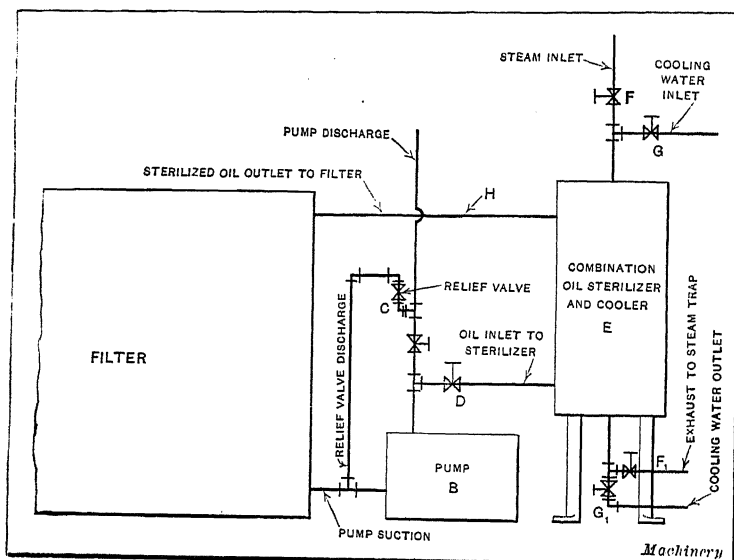


Fig. 5. Diagram showing Arrangement of Filter, Pump and Sterilizer as applied in Central Station Practice

Effective Sterilization. The systems of filtering and distributing oil described can be highly endorsed, but whether the system of sterilization is effective is a question. In order to sterilize effectively there are two points that must receive careful attention, *i. e.*, all the bacteria must be killed, after which the sterilized oil must be placed in a container which has also been sterilized in order to keep it free from germs. Even though the temperature of 140 degrees is high enough to insure the killing of all bacteria in the oil, it is doubtful whether this would be permanently effective, owing to the fact that the sterilized oil is circulated through

pipe lines and machine pans that have not been sterilized. Those who are familiar with the growth of bacteria know that they develop at a rapid rate, and so, even if all bacteria are killed in the oil treated in the sterilizer, the return of this oil to the unsterilized pipe line system would give an opportunity for the development of bacteria long before the

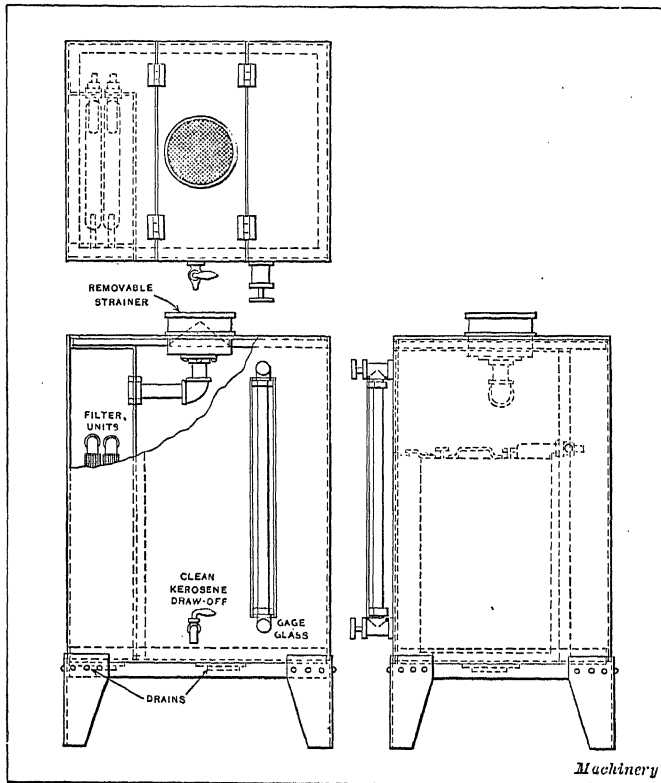


Fig. 6. Filter used with Transfer Trucks for purifying Kerosene Oil

lapse of the ten-day period. Many bacteriologists would also be inclined to question the efficacy of sterilization at 140 degrees F., as it is generally conceded that a much higher temperature is required to insure thorough sterilization. A lower temperature may be sufficient to kill existing bacteria, but the spores from which bacteria develop, which

correspond to seeds of plants, have greater vitality than the fully developed bacteria, and it requires only a few hours for these to develop into bacteria.

Planning a Central Distributing and Purifying Plant.
In planning to install a central station for the distribution and purification of oils and cutting compounds, information should be given concerning the number, size, and make of the various machine tools which are to be supplied with oil or compound, the average and maximum number of ma-

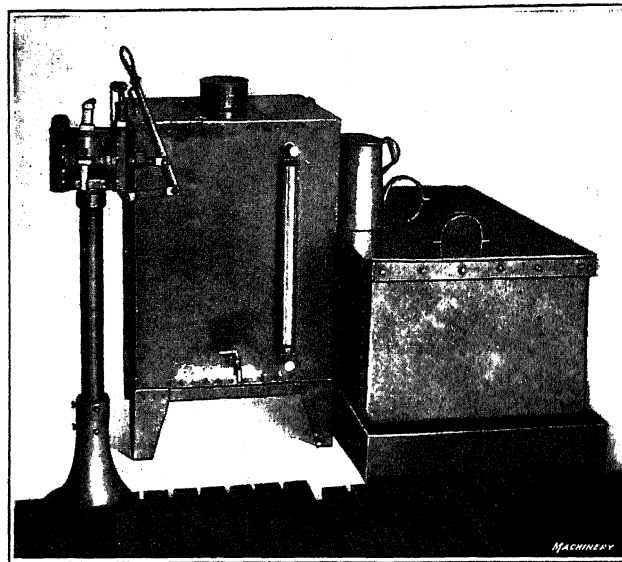


Fig. 7. View of Kerosene Oil Filter shown In Fig. 6

chines that will be operating at one time, the kind of oil or cutting compound used, and the volume which it will be desired to circulate per hour. In addition, information should be given concerning the different metals that are to be cut. In many instances it is possible to make use of the existing oil-storage and piping systems and simply add filters and sterilizers to make the system automatic.

Limitations of the central station for delivering oils and cutting compounds are the high first cost of installing such a system and the possibility of trouble arising that would

interfere with the delivery of oil or compound to the shops, thus causing loss of time and damage to cutting tools. The liability of difficulty from this source is materially reduced by installing one or more reserve pumps. Another criticism of the central distributing station is that a heavy additional expense is involved if provision is made for delivering different kinds of oils and compounds to various classes of machines in the factory. The advantages of the practice of distributing all cutting oils and compounds from a central station are as follows: Provision of clean oil, possibility of

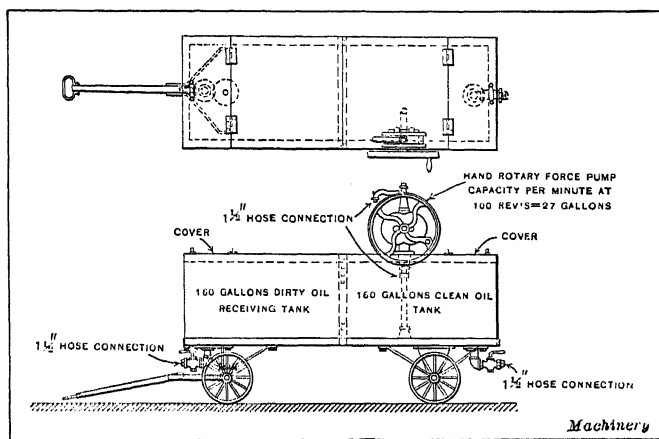


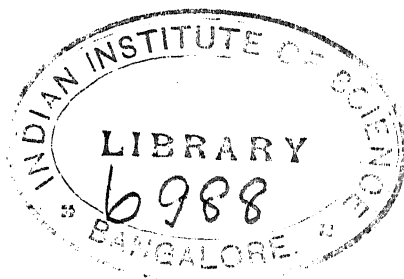
Fig. 8. Truck used for removing Dirty Oil from Machines and substituting Supply of Clean Oil

returning oil to the tools at a low temperature, sterilization of the oil to prevent infection, reduction of fire hazard, longer life for cutting oils and compounds, saving of labor in handling oil, saving of oil wasted in handling, improvement of sanitary conditions in factory, and continual stirring of soluble compounds which insures uniformity of solution.

Filters and Trucks for Transporting Oil. In some cases where it is undesirable to install a system of piping for the distribution of oil to all machines from a central station, the oil may be purified by passing it through a system of strainers and filters similar to that illustrated in Fig. 2. For this

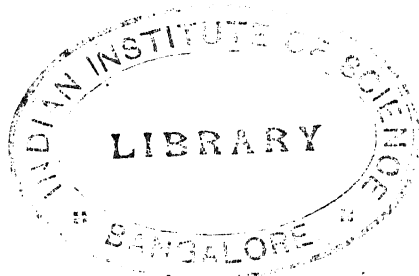
purpose separate straining and filtering outfits may be built with a capacity for handling any desired amount of oil or cutting compound. One of these small units, built for use in filtering kerosene in the factory of the Hess-Bright Mfg. Co., Philadelphia, Pa., is shown in Figs. 6 and 7. When an equipment of this kind is employed trucks are used for conveying oil to machines in the factory and for returning used oil to the filter. Fig. 8 shows an excellent truck for handling work of this kind. It will be seen that it has two compartments, each of which has a capacity for 160 gallons. The truck is taken around through the shop and dirty oil is pumped out of pump reservoirs on machines into the "dirty-oil receiving tank." After this reservoir has been cleaned (if necessary), a fresh supply of oil is pumped in from the "clean-oil tank" in the truck and the dirty oil is then taken back to the filter. A truck of this kind does away with danger of spilling oil on the floor.

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Whale oil, 14
Wing type of pump, 48



The question of the chemical action of α rays on solids has not been very thoroughly examined experimentally. As pointed out in §§ 28 and 36, the decomposition of some of the halides of the alkalis and alkaline earths has been investigated with penetrating radiation and found to be very small, in some cases almost zero. It is very fortunate that all solid substances are not attacked and chemically changed by radium radiations, as it would be impossible to carry out manometric measurements in glass or other vessels or to determine the true volume of radium emanation, if gases like oxygen, for example, were being continually liberated from the glass wall. There is no evidence of such being the case. Radium emanation may be retained in glass without the production of measurable quantities of pressure. It is very desirable to extend the investigation of the chemical effects of α rays to other solid substances both crystalline and colloidal.

It is interesting to point out that no great deviations have yet been observed of the M/N value for reactions of any substances in the liquid state, that the deviations in the solid state are all in the direction of low values of M/N , while in the gaseous state we have examples of large deviations from unity in both directions.

51. Energy Utilization of α Rays in Chemical Reactions.

In the last column of Table VII, § 36, are estimates of the percentage of the total energy of the α rays absorbed in a given system which is utilized by the resulting chemical action. The values have direct significance only in the cases where the reaction produced is opposed to the chemical free energy and therefore requires the expenditure of external energy. Values are also given, however, for the reactions proceeding with the chemical energy, in order to show that with the one large exception of the hydrogen-chlorine reaction, and to a much less degree that of hydrogen-oxygen combination, the order of the values is not very different from those of reactions opposed to the chemical free energy. This indicates that the chemical free energy does not, at ordinary temperature, play an important part in reactions produced by α particles. In other words, it appears necessary to do work on the molecules to render them chemically active,

and from the low energy utilization, it is evident that the work of the primary action involves energy quantities very much in excess of the net chemical energy, and that the amount of energy necessary to do this work is of the same order, whether the reaction is proceeding with or opposed to the chemical energy. If ionization is the intermediate step involved, this is just what would be expected. Since the energy necessary to form a pair of ions ($5.5 \cdot 10^{-11}$ ergs) is large compared with the chemical energy of reaction referred to a single molecule, the energy transformation will be small. For example, if the M/N value is unity for a reaction of which $Q = 100$ Cals., q or the heat of reaction referred to a single molecule would be $6 \cdot 10^{-12}$ ergs, and the energy utilization would be about 10%.

For most of the reactions where expense of energy is actually required the utilization factor is about 2% or less. Warburg¹⁵ has pointed out that a low order of energy transformation is one of the chief characteristics of *photochemical* action. Warburg explains this by the assumption of a primary reaction consisting in splitting the molecules into atoms, a process that would require much more energy than that involved in the finally resulting chemical reaction, were it wholly molecular in mechanism. It does not appear at all impossible that free atoms are the intermediate products in photochemical reactions, while free ions and electrons may be the intermediate products or agents in reactions produced under ionizing conditions.

It might be mentioned that the values for energy transformation given in the last column of Table VII vary considerably in reliability. The later values for water formation, and for decomposition of water, ammonia, hydrogen sulfide, and nitrogen peroxide may be accepted with assurance. The data involved in most of the other cases are older and perhaps should be verified before they can be accepted with the same degree of certainty.

52. Chemical Action Produced by Electrical Discharge in Gases.

The subject of the chemical effects of electrical discharge through gases is too large to be considered in its entirety within the limits of the present work. Attention will be confined to

¹⁵ E. Warburg, *Sitzb. Akad. Wiss. Berlin*, pp. 746-64 (1911).

those phases of the subject which are more closely related to radiochemistry and to the ionic theory of gas reactions.

As soon as it had been shown that ozone formation from oxygen is proportional to, and probably statistically equal to, the ionization (§ 33) both in the cases of α radiation and certain kinds of electronic discharge, the application of the same principle to the broader field of ozone formation by silent, spark, and other forms of electrical discharge, followed naturally. Theories were independently proposed by Kabakjian,¹⁶ by Lind,¹⁷ and by Krüger¹⁸ which were practically identical. The generalization was made that probably in all cases ozone formation in gaseous oxygen is the result of the primary ionization of oxygen by some form of electronic discharge. The quantity of ionization involved in the ozone formation is not directly related to the flow of current, but is the far greater number of ions produced in the gas by electronic shock (§ 16), which never reach the electrodes and therefore take no part in the electrical conduction, since the intensity of ionization far exceeds the limiting conditions for attaining saturation current. This predicts that the quantity of ozone formed should not be related to the current flowing, as required by direct application of Faraday's Law, but should be a much greater quantity. The experiments of Warburg¹⁹ on ozone formation by silent discharge confirm this fully. Under some conditions Warburg found that about one thousand fold as much ozone is formed as would correspond to the current, or that instead of the theoretical 96,500 coulombs required per chemical equivalent, less than 100 coulombs suffice for the production of one gram-equivalent of ozone. Hitherto it has not been possible to confirm the theory that the total ozone formation would be accounted for by the ionization by electronic shock, because we have no means of measuring the total ionization produced. Conversely the conditions under which ionization by shock have been measured²⁰ are not suitable for the formation and measurement of ozone.

Recently the subject of ozone formation in corona discharge

¹⁶ D. H. Kabakjian, *Phys. Rev.*, 31, 122-35 (1910).

¹⁷ S. C. Lind, *Trans. Amer. Electrochem. Soc.*, 21, 181-3 (1912)

¹⁸ F. Krüger, *Phys. Zeit.*, 13, 1040-3 (1912).

¹⁹ E. Warburg, *Sitzb. Akad. Wiss. Berlin*, p. 1011 (1903); *ibid.*, p. 1228 (1904). *Ann. d. Physik* 20, 734-42 (1906); *ibid.*, 20, 751 *et seq.* (1906).

²⁰ See the discussion of Townsend's work in Chapter 4.

has been investigated by Anderegg²¹ and by Rideal and Kunz.²² Anderegg expresses the opinion that oxygen atoms are probably present in all cases of ozone formation, but defers judgment as to whether ozone is formed from oxygen ions. Rideal and Kunz have paid especial attention to the distribution of ozone in the direct current corona of positive or negative sign. Their measurements of the quantity of ozone were made by two independent methods, chemical and photometrical. While the quantities of ozone formed in the positive and in the negative corona are approximately the same, the distribution differs in a marked manner in the two cases. The various ways in which ozone can be formed in the light of the radiation hypothesis (see following chapter) were also reviewed by Rideal and Kunz, and the conclusion drawn that molecules of one kind can be activated by radiation to different extents.

The combination of electrolytic hydrogen and oxygen under the influence of electrical discharge has been investigated by Kirkby.²³ The experimental conditions were regulated so as to parallel those employed by Townsend (§§ 16 and 18) in his studies of ionization by collision. Very low gas pressures (a few mms. of Hg) were used. The distance between the electrodes was varied from about 0.25 to nearly 2 cms. Kirkby found that the rate of combination is proportional to the current passing, and that about 4 molecules of H₂O are formed per pair of ions. It is very interesting to observe that this number is the same as that obtained by Lind (and practically the same as that of Scheuer) (*loc. cit.* § 48) for the same reaction under the influence of α particles. Kirkby concluded that hydrogen molecules react with uncharged oxygen atoms, which are dissociated by collision with electrons under certain conditions. Only one half of the collisions of electrons with the necessary velocity actually results in the dissociation of the oxygen molecule. For the action within the positive column Kirkby proposed a general formula: $N_{\text{H}_2\text{O}} = 7.9p \cdot e^{-42.7V/Y}$, in which p is the pressure in mms. and Y is volts.cm⁻¹. The applicability of the formula is independent of the apparatus.

²¹ F. O. Anderegg, *Journ. Amer. Chem. Soc.* 39, 2581-95 (1917).

²² E. K. Rideal and J. Kunz, *Journ. Phys. Chem.* 24, 379-93 (1920).

²³ P. J. Kirkby, *Phil. Mag.* (6) 7, 223-32 (1904); 9, 171-85 (1905); 13, 289-312 (1907); *Proc. Roy. Soc.* 85A, 151-74 (1911).

Among other gas reactions produced by electrical discharge may be mentioned the very careful investigation by Davies²⁴ in LeBlanc's laboratory at Leipzig of the decomposition and formation of ammonia in a Siemens tube. Davies investigated the reaction and equilibrium from the standpoint of the application of the mass action law. He found that the course of the reaction may be expressed by a first order equation, that the rate of decomposition is approximately proportional to the current strength, and that the rate of decomposition has a very small temperature coefficient, the rate at 100° being double that at ordinary temperature. Excess of hydrogen was found to lower the rate of decomposition, while excess of nitrogen increased it. Equilibrium attainable from both directions was almost independent of the current strength and corresponded to ammonia formation to the extent of 6% of the maximum possible. With excess of either component the equilibrium changes in favor of further ammonia decomposition. The law of mass action is not applicable to the equilibrium. The rate of ammonia formation decreases slightly in excess of nitrogen and increases slightly in excess of hydrogen; this result is in accord with those for influence of excess on the decomposition, but are not those that would be expected by analogy with influence of excess of components in water formation by α rays (§ 45), where the excess of lighter gas diminished the rate while excess of the heavier increased it. Falckenberg²⁵ and Pohl²⁶ have studied the decomposition of ammonia in a Siemens tube rather from the physical and electrical standpoint and find Faraday's law inapplicable to the relation between current flowing and quantity of ammonia decomposed. From what has been said previously in regard to ozone formation it is evident that one should not expect any direct relation between the two. To make the statement more general it is quite as unreasonable to expect equivalence between the current flowing and the chemical effect in the case of electrical discharge through gases, as it would be to expect equivalence between the total primary charge of α rays and their chemical effects. In both cases equivalence must be sought in the far greater number of ions produced by collision.

²⁴ J. H. Davies, *Zett. phys. Chem.* 64, 657-85 (1908). M. LeBlanc, *Verh. Sächs. Ges. Wiss.*, Leipzig, 66, 38-63 (1914).

²⁵ Falckenberg, *Thesis*, Berlin (1906).

²⁶ R. Pohl, *Ann. d. Physik* (4) 21, 879 (1906),

Further consideration of the experimental data on the chemical effects of the passage of electrical discharge through gases is not within the scope of this work.²⁷ In its most general aspects the subject may be regarded as having great scientific and perhaps important commercial possibilities which are well worthy of further research. For example, the possibility of an electrochemical process in which only 100 coulombs are required for the production of one chemical equivalent ought to prove attractive to the electrochemical engineer, provided the energy relations should not prove to be too unfavorable.

Besides the reactions produced by electrical discharge in gases at ordinary pressure there is a class of reactions observed at low pressures which may or may not be of chemical nature. The "clean up" of gases in spectrum tubes has been observed for many gases, but is especially puzzling for the gases of the inert series where we can not assume ordinary chemical reactions to take place. Although a mechanical or electrical explanation, such as that discussed for the hardening of X ray tubes (§§ 16 and 18) might be proposed, Collie²⁸ has recently observed the clean up of pure xenon in a manner very puzzling to explain. Xenon differs from the other inert gases in that heating does not again liberate it from the electrode or "splashed" mirror surrounding the electrode. Using platinum, aluminum and copper electrodes, Collie cleaned up more than 2 c. c. of xenon, of which he was unable to recover more than a few per cent even by chemically dissolving the electrodes, the mirror and the glass spectrum tube itself. Collie was almost forced to conclude that xenon had entered into some form of chemical combination from which it was not liberated as gas by the radical treatment employed. Radium emanation has been found by several authorities²⁹ to be cleaned up in a spectrum tube in a similar way. Since radium emanation can always be detected by its γ radiation it would be very interesting to repeat the experiments of Collie employing emanation instead of xenon to ascertain if any light would be thrown upon the nature of the "clean up."

The Research Staff of the General Electric Company of Lon-

²⁷ References to the literature will be found in the paper of Davies (*loc. cit.*).

²⁸ J. N. Collie, *Proc. Roy. Soc.* 97A, 349-54 (1920).

²⁹ Rutherford, "Radioactive Substances" (1913), p. 482.

don recently presented³⁰ the results of an investigation of the disappearance of gas in the electric discharge, from which it appears that the phenomenon is closely connected with the appearance of a glow in the discharge tube, which is believed to result from a reversible chemical action.

53. Production of Free Electrical Charges by Chemical Action.

Related to the question of the production of chemical action by ionization is the converse one as to the liberation of charges by chemical reaction. Various opinions have been expressed as to the reality of this phenomenon. There can be no question but that chemical action is often accompanied by the liberation of electrical charges, but whether or not this is ever true in a homogeneous gaseous system where there is no possibility of the accompanying influence of high temperature or of some physical process, requires careful consideration.

By introducing a gold leaf electroscope directly into a mixture of hydrogen and chlorine gases and causing them to react under the stimulation of light, J. J. Thomson³¹ showed most conclusively that no free charges are produced either in the "induction period" or during vigorous reaction. X rays projected into the same system caused the gold leaf to discharge, proving its sensitiveness, but failed to increase the rate of combination of hydrogen and chlorine as observed by the Bunsen and Roscoe actinometer. It might be mentioned parenthetically that this does not prove that X rays do not cause hydrogen and chlorine to react (proportionately to the ionization), since the sensitiveness of the gold leaf discharge to detect ions and that of the Bunsen and Roscoe actinometer to detect the disappearance of molecules by diminution in volume are of a wholly different order. Kümmell³² later thought he had found evidence contrary to that of Thomson, but Thomson's result was confirmed by a very careful investigation by LeBlanc and Vollmer,³³

³⁰ *Phil. Mag.* (6) 40, 585-611 (1920). (Conducted by N. R. Campbell and J. W. H. Ryde.)

³¹ J. J. Thomson, *Proc. Camb. Phil. Soc.*, 11, 90 (1901); "Conduction of Elect. Through Gases," 2nd Edit., p. 229.

³² G. Kümmell, *Zeit. Elektrochem.* 17, 409 (1911).

³³ M. LeBlanc and M. Vollmer, *ibid.*, 20, 494-7 (1914).

who also demonstrated for the first time a chemical effect of X rays in a gas reaction ($\text{H}_2 + \text{Cl}_2$).

On the other hand Haber and Just³⁴ have demonstrated in an extended series of experiments that the action of certain gases, including water vapor, the halides and phosgene, on alloys or amalgams of the alkali metals results in charging the metal positive owing to the liberation of electrons from its surface. Haber and Just demonstrated that temperature has an influence; iodine vapor at -79°C . had no effect, while at $+3^\circ$ there was an effect which became strong at $+13^\circ$. They showed that the combined effect of light and chemical action emits more electrons than the sum of the separate emissions. Other metals than the alkalis show an effect if the temperature be raised. Aluminium begins to show an effect at 180° , which becomes rapid at 240° . The unipolarity of the effect begins to disappear at higher temperatures. Amalgams of Cs, K, and Li gave negative ions instead of electrons. The quantities of electricity emitted were far below Faraday equivalence; for example, the formation of one gram-molecule of KCl was associated with an emission corresponding to 65 coulombs instead of 96,500.

In a study of the oxidation of metallic Na, K and alkaline earths, Reboul³⁵ showed that the electrical effects accompanying these reactions are weak and difficult to detect when the reaction is unaccompanied by some purely physical phenomenon such as emission of light, high temperature, etc. Nevertheless he does not think we are justified in discarding the idea that ionization may accompany all chemical action. Bloch³⁶ has repeated some of the earlier gas experiments of Reboul³⁷ and concludes that for the reaction $\text{NH}_3 + \text{HCl}$, ionization is doubtful; that none is produced by the reactions: $2\text{NO}_2 + \text{O}$; $\text{SO}_2 + \text{O}$ (contact method); $\text{H}_2 + \text{S}$; $\text{S} + \text{O}_2$; and decomposition of AsH_3 . Only the case $2\text{P} + 5\text{O}$ gave ionization. Pinkus³⁸ employed an electroscopic method for two reactions: for $2\text{NO} + \text{O}_2$ he found no ionization; for the reaction $\text{NO} + \text{Cl}_2$ no ionization was found for

³⁴ F. Haber and G. Just, *Ann. d. Phys.* (4) 30, 411-15 (1909); *Zeit. Elektrochem.*, 16, 275-9 (1910); 17, 592 (1911); 20, 483-5 (1914); *Ann. d. Phys.* (4) 36, 308-40 (1911).

³⁵ G. Reboul, *Le Radium*, 8, 376-81 (1911).

³⁶ L. Bloch, *Comp. rend.* 149, 278-9 (1909); *Ann. de phys. et chim.*, 22, 370-417; 441-495 (1911).

³⁷ G. Reboul, *Comp. rend.* 149, 110-3 (1909).

³⁸ A. Pinkus, *Journ. de Chim. Phys.* 16, 201-27 (1918).

equivalent quantities nor for small excesses of either gas, but for large excess of NO some ionization appeared to occur. Broglie and Brizard³⁹ concluded, after an exhaustive study of the evidence, that chemical action produces ionization only when accompanied by a physical reaction such as passage of a gas through liquid, breaking a crystalline surface, luminescence, etc. They state that there is no ionization in the case of reactions of the following classes: (1) Between gases in the cold; (2) double decomposition in liquids; (3) dry decomposition of amorphous substances at slightly elevated temperature; (4) rupture of an inactive surface by bubbling. While there is ionization in the following cases: (1) Gases prepared by wet way; (2) vigorous reactions by projection into water; (3) dry actions accompanied by the decrepitation of crystals; (4) $2\text{Na} + \text{O}$ (moist), feeble ionization; (5) reactions with incandescence, such as flames, or combustion of metals in O_2 or Cl_2 ; (6) reactions with luminescence, such as the oxidation of P and of quinine sulfate.

The case may be summed up by stating that we have no definite evidence as yet of the production of ionization or the setting free of electrical charges by any homogeneous gas reaction at ordinary temperature, but that in the case of heterogeneous reactions or gas reactions at higher temperature we have undoubted cases of the liberation of charges, which may, however, not be directly the result of the chemical action, but the secondary result of some accompanying physical occurrence.

The determination of ionization produced in gaseous explosions has been undertaken by Haselfoot and Kirkby⁴⁰ for electrolytic hydrogen and oxygen at 80 mm. pressure, and for ozonimide (HN_3) by Kirkby and Marsh.⁴¹ In the former case the M/N ratio was about 10^7 and in the latter about 100 times smaller. The explosion method has the disadvantage that whatever charges are liberated by the reaction are produced suddenly in large quantity so that the attainment of saturation current might be very difficult. However, from the small N/M ratio found it may be fairly concluded that the total liberation of charge is small compared with the number of molecules reacting,

³⁹ M. Broglie and L. Brizard, *Le Radium* 7, 164-9 (1910).

⁴⁰ E. E. Haselfoot and P. J. Kirkby, *Phil. Mag.* (6) 8, 471-81 (1904).

⁴¹ P. J. Kirkby and J. E. Marsh, *Proc. Roy. Soc.* 87A, 90-99 (1913).

because, if N were anything like the same order of magnitude as M , the fields used would have drawn a greater number of ions than was observed to the electrodes before recombination could have occurred.

Chapter 10.

Photochemical Equivalence Law.

54. Einstein's Application of the Quantum Theory to Photochemical Action.

The inclusion of this subject, which does not properly form a part of the present monograph, has a two-fold object: (1) to enable a comparison between certain points of similarity which this branch of photochemistry shares with the other radiochemical effects which have been discussed in the foregoing chapters; and (2) to present the experimental investigations which have been brought to bear upon a test of the photochemical equivalence law since the appearance of the standard works on photochemistry.

It has been recognized by physicists for some time that the idea of the continuity of light as expressed by Maxwell's theory suffices for the explanation of optical phenomena, but that certain other phenomena, such as ionization by light, photoluminescence, and "dark radiation," require the introduction of an atomistic conception of radiant energy. This step was taken by Planck in his quantum theory according to which energy is radiated or absorbed only in integral units equal to $h\nu$, in which h is the Planck's constant (6.547×10^{-27} erg. sec.) and ν is the frequency of vibration. Einstein¹ has proposed the application of Planck's quantum theory to photochemical phenomena in the following form: $N = Q/h\nu$, in which Q is the absorbed heat required for the production of the chemical action, N is the number of molecules dissociated by light of the frequency ν .

In attempting to apply Einstein's law to actual photochemical reactions it is necessary to keep in mind that it applies only to the *primary light reaction*. As will be seen later, secondary reaction may intervene in such a way that the total quantity

¹ A. Einstein, *Ann. d. Physik* (4) 37, 832-8; 38, 881-4; 888 (1912). Also *ibid.* (4) 17, 132-48 (1905).

of chemical action resulting from the primary action may be either equivalent to it, or greatly in excess or deficiency, depending upon circumstances. In general it is not possible to measure the quantity of primary reaction directly, but only through the production of some secondary reaction. In order, therefore, that the test of the equivalence required by Einstein's photochemical law shall have any significance it is necessary to be able to measure a secondary reaction which is really equivalent to the primary. From the terminology of photochemistry the term *acceptor* has been used to designate the substance acted on by the product of the primary light reaction. Evidently the first requisite in testing the photochemical equivalence law is an acceptor which will give a measurable secondary reaction that is equivalent to the primary. There is as yet no theory according to which the action of a given acceptor toward a given primary product can be predicted. It is necessary in each case to try by experiment. Early failures to find "suitable" acceptors for the reactions investigated have rather retarded progress, but as experience is accumulated a more rapid development of the subject may be expected in the future.

55. Experimental Tests of the Law of Photochemical Equivalence.

Warburg² was one of the first to undertake experiments in this direction and was followed by Bodenstein, Lewis, and yet more recently by Nernst, his co-workers, and others. The results of the earlier work were summarized in 1913 by Bodenstein.³ The following Table XV gives a list of reactions according to Bodenstein which he terms "primary light reactions," in which the number of molecules (M) acted on in the primary action are either equal to $h\nu$ or exceed it by small multiples. They may be regarded as cases in which Einstein's law is at least approximately applicable.

At the time that Bodenstein made the classification presented in Table XV he was of the opinion that the primary light reactions are the result of direct action of the positively charged ions left after the removal of an electron from the molecule. As

² E. Warburg, Extended series of papers in the *Sitzb. Berlin Akad. Wiss.*
See later refs.

³ M. Bodenstein, *Zeit. phys. Chem.* 85, 333 (1913).

TABLE XV

Primary Light Reactions According to Bodenstein

<i>Reaction</i>	<i>Authority</i>	<i>Absorption</i>	<i>hν/M</i>
$2\text{HI} = \text{H}_2 + \text{I}_2$	B. ⁴	weak	?
$3\text{O}_2 = 2\text{O}_3$	R. ⁵ W. ⁶	weak strong	1 for 2 $\ddot{\text{O}}_3$ (measd.)
$2\text{NH}_3 = \text{N}_2 + 3\text{H}_2$	R. ⁷ W. ⁸	strong	4 (measd.)
$2\text{H}_2\text{O} = 2\text{H}_2 + \text{O}_2$	Not yet measd. without photochemical re-combination.		
Anthracene→			1 to 0.7 (calcd.)
dianthracene	L. & W. ⁹	medium	3 (calcd. by B.)
Decomp. Levulose	B. & G. ¹⁰	medium	1.4 (calcd.)
$\text{C}_6\text{H}_4\text{NO}_2\text{CHO} \rightarrow$	W. & K. ¹¹	medium	9 (calcd.)
$\text{C}_6\text{H}_4\text{NOCOOH}$		strong	
$\text{S}\lambda = \text{S}\mu$	W. ¹²	medium	4 to 5 (calcd.)
Quinine oxidation by chromic acid	L. & F. ¹³	medium	1.5 (calcd.)
$2\text{O}_3 = 3\text{O}_2$ (by Cl_2)	W. ¹⁴	medium	1.7 (calcd.) 0.8 (calcd. by B.)

already stated, on account of the experimental evidence to the contrary Bodenstein¹⁵ was forced to abandon his theory and to adopt the idea of Stark¹⁶ that the primary light effect consists in *loosening* the valence electrons in such a manner as to render the molecule chemically active. This change of theory in no way affects the applicability of Bodenstein's idea of primary light reactions, for which he prescribes the following characteristics: (1) Proportionality between the quantity of chemical

⁴M. Bodenstein, *Zeit. phys. Chem.* 22, 23 (1897); 61, 447 (1907).

⁶E. Regener, *Ann. d. Physik* (4) 20, 1033 (1906).

⁸E. Warburg, *Sitzb. Akad. Wiss. Berlin*, 1912, 216.

⁷E. Regener, *loc. cit.*

⁹E. Warburg, *Sitzb. Akad. Wiss. Berlin*, 1911, 746; 1912, 216.

¹⁰R. Luther and F. Weigert, *Zeit. phys. Chem.*, 51, 297; 53; 385 (1905).

¹¹D. Berthelot and H. Gaudechon, *Comp. rend.* 156, 707 (1913).

¹²F. Weigert and L. Kummerer, *Ber.* 46, 1207 (1913).

¹³A. Wigand, *Zeit. phys. Chem.*, 77, 423 (1911).

¹⁴R. Luther and G. S. Forbes, *ibid.*, 41, 1 (1902)

¹⁵F. Weigert, *ibid.*, 80, 103; *Zeit. Elektrochem.*, 14, 591 (1908).

¹⁶M. Bodenstein, *Zeit. Elektrochem.*, 22, 53-61 (1916).

¹⁷J. Stark, "Atomdynamik," Leipzig, 1911, Vol. II, p. 207.

reaction and the absorbed energy—with a corresponding law for reaction velocity. (2) Absence of influence of foreign substances, and (3) absence of influence of temperature, insofar as they do not influence the absorption of light. (4) One molecule reacting for each quantum of energy absorbed or for a small number of the latter.

Under secondary light reactions Bodenstein classed those which show a great excess over or deficiency from the requirements of Einstein's theory, and originally assumed that the excess action is due to the multiplied effect of the free wandering electrons, as already explained in the previous chapter. Upon being forced to abandon this theory for the same reason as in the case of the primary reactions, Bodenstein makes the assumption that a molecule which has received light energy (in the form of loosened valence electrons) does not lose it on combining with another atom or molecule, but produces a compound which is capable of imparting this energy to certain other molecules with which it comes into contact. To take the case of the $\text{H}_2\text{—Cl}_2$ reaction, he assumes that Cl_2 is activated, combines with ordinary H_2 molecules to form activated HCl which can impart its activity to Cl_2 and to O_2 (to explain dissipation of activity by inhibitors), but not to neutral gases like N_2 , nor to H_2 . In the following section will be presented a theory by Nernst assuming atomization of Cl_2 as the primary action. Without any distinction at present as to which theory has greater probability, Bodenstein's classification of the secondary light reactions has the same experimental weight as it originally carried and is therefore given in the following Table XVI.

Luther and Goldberg¹⁷ have shown that in all the photo-chlorinations investigated by them oxygen acts as an inhibitor, and Bodenstein makes the generalization that oxygen inhibits all the secondary photochemical reactions except those in which it takes part as an oxydizing agent. The data of Bodenstein and Dux¹⁸ on the kinetics of the photochemical interaction of hydrogen and chlorine served as a basis for Bodenstein's general photochemical theory, which he then applied to other photochemical reactions with the following modifications, which have been

¹⁷ R. Luther and E. Goldberg, *Zeit. phys. Chem.*, 56, 43 (1906).

¹⁸ M. Bodenstein and W. Dux, *ibid.*, 85, 297-328 (1913).

transformed by the writer into terms corresponding to his later theory instead of the original electronic theory:

(1) It is not always the substance primarily acted on by light which becomes activated for the secondary reaction.

(2) The velocity of the secondary effective reaction is not always excessively large compared with the ineffective reversion of the primarily affected substance to its original form.

(3) The secondary reaction is not always so great that the primary one can be neglected in comparison, as in the case of hydrogen and chlorine.

(4) Oxygen inhibition can be absent in case oxygen is the substance activated in the secondary reaction.

(5) Other substances can act as inhibitors and either take the place of or act jointly with oxygen.

In Table XVI the reactions are divided by Bodenstein into three classes: I. Those in which oxygen acts as inhibitor. II. Those in which oxygen is one of the components of the reaction and does not inhibit. III. Those in which the primary reaction can not be neglected in comparison with the secondary reaction. I_0 refers to the light absorption by A, the substance primarily acted on. B is the substance activated in the secondary reaction. C is in some cases a third reacting substance. dx/dt indicates velocity of chemical reaction in the usual differential form.

Recently a more rigorous test of Einstein's photochemical equivalence law has been made by Nernst³⁸ and Frl. Pusch.³⁹ Nernst emphasizes the necessity of paying attention to the primary reaction and of choosing an acceptor which neither multiplies nor diminishes the products of the primary action, but directly transforms them into the equivalent quantity of finally measured product. Frl. Pusch found hydrogen to be a very unsuitable acceptor in its reaction with bromine, the amount of action falling far short of theory. In an experiment with solar radiation of ten hours' duration, the quantity of bromine combined was 0.02 g., where 2.3 grams were predicted by theory. In experiments with a "nitra" (nitrogen filled) lamp as source of light, it was found that heptane, hexane and toluene all combine with bromine at a rate greater than theory, but hexahydroben-

³⁸ W. Nernst, *Zeit. Elektrochem.*, 24, 335-6 (1918).

³⁹ Frl. L. Pusch, *ibid.*, 24, 336-9 (1918).

TABLE XVI

Secondary Light Reactions According to Bodenstein

I. Equation $\frac{dx}{dt} = k \cdot \frac{I_0 \cdot (A) \cdot (B)}{(O_2)}$				Equation Observed	M/hv
Reaction	Authority	A.	B.		
$H_2 + Cl_2 = 2HCl$	B. & D. ¹⁹	Cl_2	Cl_2	$k \cdot (Cl_2)^2 / (O_2)$	10^6
$2O_3 = 3O_2$	R. ²⁰ v B. ²¹ W. ²²	O_3	O_3	$k \cdot (O_3)^2 / (O_2)$	10^2-10^3
Hydrolysis of acetone	H. & W. ²³	.....	.....	.....	200
Oxalic acid +	B. ²⁴	UO_2	$C_2H_4O_4$	$k(UO_2 + C_2H_4O_4) \cdot C_2H_4O_4$	500
Uranyl nitrate		$C_2H_4O_4$			
Hydrolysis of H_2PtCl_6	B. & J. ²⁵	H_2PtCl_6	H_2PtCl_6	$k \cdot (H_2PtCl_6)^2$	1 or 2
$2H_2O_2 = 2H_2O + O_2$	T. ²⁶ H. & W. ²⁷	H_2O_2	H_2O_2	$k \cdot (H_2O_2)^2 / O_2$	100
Quinine + O_2	W. ²⁸	Ch-I ²⁹	Ch-II ²⁹	$k \cdot \frac{(Ch)^2}{(O_2)}$	1/200
Bleaching of dyes	W. ³⁰ Wi. ³¹ (K) ³²	Dye	Dye	.....	1/200 (1/500)
$4HI + O_2 = 2I_2 + 4H_2O$	P. ³³	I'	O_2	$k \cdot (I') \cdot (O_2)$	10^6
$CHI_3 + O_2 = \dots$	P. ³⁴	CHI_3	O_2	$k \cdot (CHI_3) \cdot (O_2) ?$	1 to 15

$\text{CO} + \text{Cl}_2 = \text{COCl}_2$	Wn. ²⁵ C. & G. ²⁶	III. Equation dx/dt		$dx/dt = m + n/(\text{O}_2)$ for $\text{Cl}_2 + \text{CO}$ const. $dx/dt = k(\text{CO}) \cdot (\text{Cl})^{1-2}$	100
		Cl_2	Cl_2		
$\text{Br}_2 + \text{C}_7\text{H}_8 = \text{HBr} + \text{C}_7\text{H}_7\text{Br}$	B. & C. ²⁷	Br_2	Br_2	$k(\text{Br}_2) \cdot (\text{C}_7\text{H}_8)$	10^6

²⁵ M. Bodenstein and W. Dux, *Zeit. phys. Chem.*, 85, 297-328 (1913).

²⁶ E. Regener, *Ann. d. Physik* (4) 20, 1033 (1906).

²⁷ Frl. E. v. Bahr, *ibid.* (4) 33, 598 (1910).

²⁸ F. Weigert, *Zeit. phys. Chem.*, 80, 78 (1912).

²⁹ V. Henri and R. Wurmser, *Comp. rend.* 156, 1012 (1913).

³⁰ M. Boll, *ibid.*, 156, 1891 (1913).

³¹ M. Boll and P. Job, *ibid.*, 154, 881 (1912) 155, 826 (1912); 156, 138, 691 (1913).

³² A. Tian, *ibid.*, 151, 1040 (1910); 156, 1879 (1913).

³³ V. Henri and R. Wurmser, *loc. cit.*

³⁴ F. Weigert, *Nernst Festschrift*, p. 464.

³⁵ Ch-I is undissociated quinine sulfate; Ch-II is quinine ion or the free base.

³⁶ F. Weigert, *loc. cit.* (9).

³⁷ C. Winther, *Zeit. weiss. Phot.* 11, 92 (1911).

³⁸ W. Kistiakowski, *Zeit. phys. Chem.*, 85, 431 (1900).

³⁹ J. Plotnikow, *ibid.*, 58, 214 (1907).

⁴⁰ J. Plotnikow, *ibid.*, 75, 337; 85 (1910).

⁴¹ M. Wildermann, *ibid.*, 42, 257 (1903); *Phil. Trans. Roy. Soc. Lond.* 199A, 337 (1902).

⁴² D. L. Chapman and F. H. Gee, *Journ. Chem. Soc. Lond.*, 99^{II}, 1726 (1911).

⁴³ L. Bruner and S. Czernecki, *Bull. Acad. Cracovie A*, 1910, p. 576.

zene appeared to be a suitable acceptor, and the following results were obtained by Frl. Pusch for several different exposures.

TABLE XVII

Test of Photochemical Equivalence Law, According to Frl. Pusch

Reaction: Bromine + Hexahydrobenzene.

Hours	Milligrams of Bromine Combined	
	(Found)	Calcd. (Einstein's Law)
8.25	2.08	1.82
22.33	5.95	5.38
20.25	5.72	5.10
24.25	5.66	5.70
24.00	5.82	5.51

Since the appearance of Bodenstein's classification, Warburg has tested the applicability of Einstein's law for a number of additional reactions. For the decomposition of ozone⁴⁰ he finds that, in dilute mixtures where the total pressure is one atmosphere, the secondary reaction furnishes a new confirmation of the law. Photolysis in aqueous solution was examined in the case of decomposition of nitrates to nitrites⁴¹ using three wave lengths separately of the zinc arc: $\lambda = 0.214, 0.257, \text{ and } 0.274\mu$, respectively. The reaction was faster in slightly alkaline than in acid solution, was independent of the cation and of the degree of electrolytic dissociation. Einstein's law was not followed, the reaction being greater for short than for long wave lengths. The effect of the solute was suggested as the probable cause. The conversion of isomers was examined for the reactions: maleic \rightarrow fumaric acid and the reverse action.⁴² The chemical action found was about 4-13% of theory. The rate for maleic \rightarrow fumaric increased with increase of λ but in a much greater ratio. The rate of the reverse reaction showed the opposite effect, thus contraverting

⁴⁰ E. Warburg, *Ber. Berlin Akad. Wiss.*, 1913, 644-59.

⁴¹ E. Warburg, *ibid.*, 1918, 1228-46.

⁴² E. Warburg, *ibid.*, 1919, 960-74.

the Einstein law. The effect of concentration was not great. Further tests in the case of ammonia decomposition⁴³ showed that either the law does not apply or that much ammonia is reformed. The application of the law was also not successful for the photolysis of HBr.⁴⁴

56. Comparison of Photochemical Equivalence Law and Ionic-Chemical Equivalence.

Reference to Tables VII, XV and XVI will show that we have the same kinds of variation between theory and experiment both in photochemical and in α ray reactions. In both we have a number of experimentally investigated reactions in which agreement with theory is as good as could be expected in the present status of experimentation. We also have in both cases large departures from theory in either direction. On account of these points of similarity the question naturally presents itself as to whether the mechanism of reaction is not identical for the two different forms of radiation.

The most striking case of greatly excessive action among those hitherto investigated by α radiation has been shown to be that of hydrogen and chlorine where reaction exceeds theory by something like 10^4 . Among the photochemical reactions we find the same reaction exceeding theory by 10^6 . Bodenstein (*loc. cit.*) has expressed the view that the same mechanism must control both reactions. It would be of great interest to measure the increasing activity of hydrogen-chlorine mixtures with different forms of radiation to see whether the reactivity increases in the same proportion for all.

To explain the mechanism by which such large excess over theory can be attained, we have first the free electron theory of Bodenstein, which had to be abandoned as an explanation of photochemical effects, on account of the experimental demonstration of the absence of free electrons; but which may still hold for the α ray reactions, unless it be admitted with Bodenstein, that by analogy the same mechanism must hold for both. Second, we have the theory of loosened electrons of Stark for which Bodenstein has made the assumption that the light energy is retained after reaction and is imparted to other molecules, ren-

⁴³ E. Warburg, *Ber. Berlin Akad. Wiss.*, 1914, 872-85.

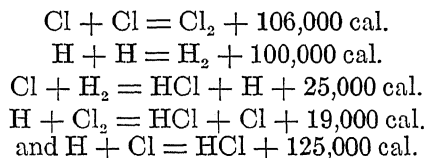
⁴⁴ E. Warburg, *ibid.*, 1916, 314-29.

dering them active. While there may be some question as to the probability of this theory, it has the advantage of very general applicability. In the following section it will be seen that Nernst has proposed an atomistic theory to account for the hydrogen-chlorine reaction, which is based on purely thermodynamic considerations. While it has great probability for that specific reaction it appears to be inapplicable directly to the other cases of excessive reaction. W. C. M. Lewis has proposed a radiation theory which is discussed in § 58.

The cases in which large deficiencies from theory are observed have all been explained up to the present by immediate reversal of the primary reaction. In this sense, an acceptor is a substance which combines with the products of the primary reaction without allowing them to recombine among themselves. On the other hand, the additional condition must be imposed upon a "suitable" acceptor, from the standpoint of photochemical equivalence, that it shall not by any other process multiply the output of the primary reaction.

57. Mechanism Proposed by Nernst for the Hydrogen-Chlorine Photo-Reaction.

Nernst has recently applied his heat theorem⁴⁵ to calculate the following heats of reaction:



From the known absorption of chlorine for light of different wave lengths it can be calculated by the quantum theory within what spectral region chlorine can be dissociated into atoms. The calculation shows that this can be accomplished by the wave lengths known to produce chemical combination of hydrogen and chlorine and the assumption of the existence of free Cl atoms for the propagation of the photo-reaction is therefore justified. The heat of reaction shows that the combination of a Cl atom with a H₂ molecule and the subsequent splitting of

⁴⁵ W. Nernst, *Sitzb. Berlin Akad. Wiss.*, 1911, 65-90; also "Grundlagen d. neuen Wärmesatzes" (1918), p. 133.

this unstable product to HCl and a free H atom take place with a large heat evolution, and therefore in the direction of spontaneous reaction according to the chemical free energy. Moreover, when a free H atom (just produced by the foregoing reaction) unites with a Cl_2 molecule we again have a reaction of the same nature. The Cl atom liberated by the latter reaction brings us back to the original system, and a cycle has been completed which may repeat itself indefinitely, except for the cross reaction of H and Cl atoms, and for the inhibitive effect of oxygen, which is assumed to remove the free Cl atoms from the field of action. By this purely thermodynamic method Nernst explains the multiplied secondary reaction in a mixture of H_2 and Cl_2 , which accounts for the large departure from Einstein's law through the action of *free atoms*. In further support of the theory, Nernst calculates that a similar continuous cycle in the case of hydrogen and bromine is impossible, because one of the steps, $\text{Br} + \text{H}_2$, would not proceed spontaneously on account of a negative heat of reaction, $-15,000$ cal. And of course it is well known that a mixture of $\text{H}_2 + \text{Br}_2$ is not light sensitive at ordinary temperature. The further application of this or similar mechanisms to explain other cases of excessive action has not been attempted, but it is not without interest to note that in the only other two cases where the M/N value is as high as 10^6 (Table XVI), we have halide and hydrogen present in the system.

58. General Radiation Theory of Chemical Action.

In an extended series of investigations, Lewis and his co-workers⁴⁶ have proposed a radiation theory of chemical action which appears to be of fundamental importance in chemical kinetics, and which also has afforded additional confirmation of the applicability of Einstein's law. A general review of Lewis's theory and his deductions from it is pertinent to the subject of the present chapter.

It has long been recognized that the usual positive temperature coefficient of chemical reaction, which is of the order of a

⁴⁶ A. Lamble and W. C. McC. Lewis, *Journ. Chem. Soc. Lond.*, 105_{II}, 2330-42 (1914); 107_I, 233-48 (1915). R. H. Callow and Lewis, *ibid.*, 109_I, 55-67 (1916). R. O. Griffith and Lewis, *ibid.*, 109_I, 67-83 (1916). Lewis, *ibid.*, 109_{II}, 796-815 (1916). R. O. Griffith, A. Lamble and Lewis, *ibid.*, 111_I, 389-95 (1917). Lewis, *ibid.*, 11_I, 457-69; 111_{II}, 1086-1102 (1917); 113, 471-92 (1918); 115, 182-93 (1919); Rep. Brit. Assoc. (1915), p. 394.

2 to 3 fold increase for an interval of 10°C. , can not be explained by the mere increase of kinetic energy of the reacting molecules. It has also been rather generally assumed that the molecules, before they react, must in some way be *activated*, and that this process is the one influenced by increase of temperature.

In 1889 Arrhenius⁴⁷ deduced a relation based on the assumption of a mass action equilibrium between active and inactive molecules, of the form: $d \log k/d T = A/T^2$, in which k is the velocity constant of chemical action, T is the absolute temperature, and A is one half of the energy required to change 1 Mol of inactive to active modification. This formula has since been shown to be of very general experimental applicability, although its theoretical basis is no longer tenable for the following reasons. The conception of Arrhenius, or indeed any other theory that attempts to explain velocity of reaction as controlled by temperature, leads directly to the consideration of the effect of catalysts, and that of Arrhenius to the prediction that the temperature coefficient should be diminished in a homogeneous system by the increase of the concentration of the catalyst. This prediction has not been confirmed by later work, including that of Lewis, who found that the temperature coefficient of the rate of hydrolysis of methyl acetate is independent of the concentration of acid. Recent work of Taylor⁴⁸ in the laboratory of Arrhenius has cast further doubt upon the existence of "active" molecules (in the sense of Arrhenius).

In 1914 Marcelin⁴⁹ treated the effect of temperature on velocity of reaction as a purely physical one dependent on the increase of the internal energy of the reacting molecule, and arrived at a formulation similar to that of Arrhenius: $d \log k/d T = E/RT^2$, in which E is defined as the critical energy that must be absorbed by the molecule to render it active. Lewis suggests that E be called the *critical increment* to emphasize that it is the *excess* energy that must be absorbed by the activated molecules above the average energy possessed by all molecules.

Rice⁵⁰ has developed in more exact mathematical form the same equation: $d \log k/d T = (V_c - V_m + 1/2(RT))/RT^2$, in

⁴⁷ Sv. Arrhenius, *Zeit. phys. Chem.*, 4, 226-48 (1889).

⁴⁸ H. S. Taylor, *Medd. Vetenskapsakad. Nobclinst.* 2, No. 34 (1912).

⁴⁹ R. Marcelin, *Comp. rend.* 158, 161 (1914).

⁵⁰ J. Rice, *Rep. Brit. Assoc.* (1915), p. 397.

which V_m is the mean value of the potential energy of the molecules and V_c is the critical value which must be attained before chemical reaction ensues. Rice's formulation was used by Lewis in the development of the radiation theory applied to catalysis and later to chemical action in general. The application to catalysis has been adopted and explained by Rideal and Taylor.⁵¹

Lewis (*loc. cit.*) advances the hypothesis that the energy increment is imparted to the molecule by means of infra-red radiation, and that the Einstein Law is applicable to the energy absorption. The energy increment can be calculated directly from the temperature coefficient, as follows: $\log k_{35}/k_{25} = E/R(1/298 - 1/308)$. For the hydrolysis of methyl acetate the coefficient for a 10° interval at ordinary temperature is about 2.5, from which E is calculated to be 16,800 cal. per g.mol., or 1.03×10^{-12} ergs per single molecule. From Einstein's law Lewis calculates that for the infra-red radiation of $\lambda = 7.5\mu$ for methyl acetate (Coblentz⁵²), $h\nu$ should be 0.262×10^{-12} ergs, or that $4h\nu$ should suffice to furnish the required energy E . Conversely Lewis has calculated from the velocity of the H ion (electrolytic) and its probable free path that it would have a vibration frequency falling in the region of the known absorption.

Lewis's suggestion that catalysis is in general a radiation phenomenon is supported by the theory of Trautz⁵³ and later by that of Krüger,⁵⁴ who showed that the processes of solution, solution pressure, solubility and electrolytic dissociation can be explained on the basis of radiation, which in turn can be related to the dielectric constant of the solvent. According to Lewis's conception the function of a catalyst is to absorb the infra-red radiation of the chemical system and to transfer the energy to the reacting molecule. In this sense catalysis is evidently but a special case of chemical reaction, where the absorption is accomplished by the catalyst instead of by the reacting substance itself. All reactions taking place in a solvent must be regarded as catalytic.

A still further step has been taken by Lewis (*loc. cit.*) in

⁵¹ E. Rideal and H. S. Taylor, "Catalysis in Theory and Practice" (1919), p. 58 *et seq.*

⁵² W. W. Coblentz, Pub. Carnegie Inst., Washington, 1905, 35.

⁵³ M. Trautz, *Zeit. wiss. Phot.*, 4, 160 (1906).

⁵⁴ H. Krüger, *Zeit. Elektrochem.*, 17, 453 (1911).

applying his theory to uncatalyzed homogeneous gas reactions. Strictly, Einstein's law is applicable only when n (index of refraction) = 1, which is true only in the case of gases. Lewis's theory applies to bimolecular homogeneous reactions of the type $2\text{HI} = \text{H}_2 + \text{I}_2$, with a fairly good agreement with the Einstein law. Heterogeneous (contact) catalysis can also be explained by Lewis's theory on the basis of Langmuir's⁵⁵ hypothesis regarding the spacial distribution of molecules and atoms at the interface between two phases. The energy increment is lowered at the contact surface, which is in agreement with the lower temperature coefficients of heterogeneous chemical reactions.

Lewis⁵⁶ has recently pointed out the anomalous case of *monomolecular* homogeneous gas reactions, which differ from the bimolecular reactions in the pronounced failure of Einstein's law. The value of the velocity constant for the rate of dissociation of PH_3 observed by Trautz and Bhandarkar⁵⁷ is about 10^7 greater than calculated by Lewis from Einstein's law on the assumption of continuous absorption. For discontinuous absorption the discrepancy becomes still greater. In view of the approximate agreement for bimolecular reactions this great departure for monomolecular reactions is all the more notable.

Baly⁵⁸ has applied the quantum theory to spectroscopic and fluorescent phenomena. According to his theory a molecule may absorb radiation by quanta of a given frequency and radiate a larger number of quanta as a result of chemical action at a lower frequency. Chemical action, excessive from the standpoint of Einstein's law, can then be explained by re-absorption of this internal radiation, a process that will result in further chemical action that may be multiplied to very large quantities from one quantum primarily absorbed. Baly proposes this explanation for the large excess observed in the thermal decomposition of phosphine and also for the photochemical decomposition of hydrogen peroxide and hydrolysis of acetone.⁵⁹

It should be mentioned that Perrin⁶⁰ independently arrived

⁵⁵ I. Langmuir, *Journ. Amer. Chem. Soc.* 38, 2221 (1916).

⁵⁶ W. C. McC. Lewis, *Phil. Mag.* (6) 39, 26-31 (1920).

⁵⁷ M. Trautz and D. S. Bhandarkar, *Zeit. anorg. Chem.* 106, 95 (1919).

⁵⁸ E. C. C. Baly, *Phil. Mag.* (6) 40, 1-15; 15-31 (1920).

⁵⁹ V. Henri and R. Wurmser, *Comp. rend.* 156, 1012 (1913).

⁶⁰ J. Perrin, *Ann. de Physique* (9) 11, 5-108 (1919).

at a general radiation theory of chemical action which is very similar to that of Lewis.

The type of radiation that is involved in Lewis's theory is very different from the corpuscular forms that are treated in this monograph and also from those of the usual photochemical effects. In the infra-red absorption the energy increment is not a large fraction of the chemical energy of the reaction, whereas, in the case of the corpuscular and photochemical radiation effects, the energy applied is usually largely in excess of the net chemical energy involved in the reaction.

With reference to the emission of infra-red radiation by chemical reactions, the recent work of David⁶¹ should be cited, who has shown that the explosive combination of oxygen with coal gas and with hydrogen results in the emission of radiation of wave lengths $\lambda = 2.8\mu$ and 4.4μ . Although the temperature of reaction in the experiments of David is estimated at 1200° , he is of the opinion that the radiation is due to the chemical action and not to temperature effect.

Further contributions to the radiation theory of chemical action have been very recently made by Langmuir,⁶² Rideal,⁶³ Lindemann⁶⁴ and Tolman.⁶⁵ Langmuir makes a fundamental inquiry into the basis of the radiation hypothesis of chemical action and concludes (1) that it has not been satisfactorily demonstrated that the radiation emitted by a chemical action, as calculated from the temperature coefficient, falls in the absorption region of the system; (2) that the total radiation is not nearly sufficient to account for chemical activation and that the radiation hypothesis is untenable. Langmuir believes that the internal energy of the molecule is the ultimate source of its activation. Lindeman points out (as does Langmuir also) that according to the radiation hypothesis many reactions should be photo-sensitive which fail to exhibit this effect. Tolman adopts the view of Lewis, Perrin and Marcelin that the similar form of the Arrhenius equation and the Wien radiation law justifies the radiation hypothesis of chemical action. Tolman employs

⁶¹ W. T. David, *Phil. Mag.* (6) 39, 66-83; 84-95 (1920). *Trans. Roy. Soc. Lond.*, 211, 375; *Proc.*, 85, 537 (1911).

⁶² I. Langmuir, *J. Am. Chem. Soc.*, 42, 2190-2205 (1920).

⁶³ Eric K. Rideal, *Phil. Mag.* (6) 40, 461-6 (1920).

⁶⁴ F. A. Lindemann, *ibid.* (6) 40, 671-4 (1920).

⁶⁵ R. C. Tolman, *J. Am. Chem. Soc.*, 42, 2506-28 (1920).

the principles of statistical mechanics to develop the Rice-Marcelin equation and also makes many other applications important to chemical kinetics. Rideal employs a formula of Langmuir and Dushman to develop the equation for velocity of reaction: $\frac{dn}{dt} = \nu \cdot e^{\frac{-h\nu}{kT}}$, in which n is the number of molecules reacting per second, ν is the frequency, and all other symbols having the usual meaning. Applying this to the decomposition of PH_3 , the velocity constant is calculated to be 3.5×10^{-3} , the same order of magnitude as that observed 10.2×10^{-3} .

Daniels and Johnston⁶⁸ have recently investigated the thermal and photochemical decomposition of gaseous N_2O_5 . The thermal action is monomolecular and proceeds at room temperature. The critical increment as calculated from the temperature of the velocity of decomposition is independent of the temperature. Its value, 24,700 calories, indicates according to the radiation theory that the reaction should be catalyzed by light of wave length = 1.16μ . Photochemical investigation failed to confirm this prediction. Light in the region $400\text{--}460\mu$ does accelerate the decomposition, but only in the presence of NO_2 . The interesting theory is proposed that the catalytic effect of NO_2 is due to its absorption of blue light over a wide spectral range and that through fluorescence, radiation is emitted in the infra-red region where its absorption lines coincide with those of N_2O_5 , causing decomposition of the latter. Experimental evidence of the actual fluorescence of the NO_2 and of the decomposition of N_2O_5 by radiation in the infra-red region remains to be obtained.

⁶⁸ F. Daniels and E. H. Johnston, *J. Am. Chem. Soc.*, 43, 53-81 (1921).

Chapter 11.

Positive Rays and Recoil Atoms.

59. General Nature of Positive Rays.

In 1886 it was observed by Goldstein¹ that if he used a perforated cathode in examining electrical discharge through air at low pressure, luminous beams of rays could be seen traversing the space back of the cathode, *i. e.* on the side away from the anode, which apparently came through the channels in the cathode. On account of their mode of formation or demonstration Goldstein called them "canal" rays. It has since been shown that they are the positively charged gaseous ions which, at low gas pressure, attain sufficient velocity toward the cathode or negative pole to carry them through the perforations into the space behind, where they can be observed by means of phosphorescent screens or by their action on the photographic plate.

In 1898 Wien² demonstrated the deflection of the canal rays by a strong magnetic field. Since this time J. J. Thomson³ has conducted a series of investigations which have resulted in discoveries of the greatest importance both to physics and chemistry. It has been recommended by Thomson⁴ that the more correctly descriptive term, *positive rays of electricity*, be used instead of canal rays.

Thomson⁴ has elaborated a technique to determine by means of deflection in a combined magnetic and electrostatic field the e/m value of each type of positive ray. The effects due to the superposition of the electric and magnetic fields simultaneously applied have been analyzed by Thomson in the following way: If the forces are applied parallel to the axis of z , the y and z deflections of the particle are given by the two equations:

¹ E. Goldstein, *Sitzb. Akad. Wiss.*, Berlin, 1886, p. 691; *Wied. Ann.*, 64, 38 (1898).

² W. Wien, *Verh. deut. phys. Ges.*, 17, .. (1898).

³ J. J. Thomson, *Phil. Mag.* (6) 21, 225-49 (1911); 24, 209-53 (1912).

⁴ J. J. Thomson, "Rays of Positive Electricity" (1913).

$y = e/mv.A$ and $z = e/mv^2.B$, in which A and B depend only on the strengths of the magnetic and electrical fields, respectively, and the distance of the projection from the point of deflection, and can be made constant for a given experiment. In the absence of any field all positive rays would pass through the narrow aperture in the cathode and be recorded on the photographic plate at the same spot $x = l$, the distance of the plate from the source. Under the selective action of the two forces the particles are sorted out and no two strike the plate at the same spot unless they are moving with the same velocity and have the same e/m value. By combining the two equations just given above we have: $v = y/z.B/A$ and $e/m = y^2/z.B/A^2$. The first shows that y/z is constant for all particles moving with a given velocity v , no matter what their charge or mass is, and, therefore, will all lie on the plate in a straight line passing through the undeflected position of the particles. The second equation shows that for the same kind of particles, y^2/z is constant no matter what their velocity; hence, all particles of the same kind will trace on the plate a parabola with its vertex at the undeflected position of the particles. Each parabola will represent a different kind of particle. This principle has been used by Thomson and his co-workers as a method of positive ray analysis, which will be described in the following section.

60. Thomson's Method of Positive Ray Analysis.

Thomson's experimental method has been very fully described in his "Rays of Positive Electricity." The latest modification of the apparatus, termed mass-spectrograph, has recently been thoroughly described by Aston.⁵ Only a few of the most important experimental features will be mentioned here before passing on to a consideration of the results. A very large spherical bulb (20 cms. diameter) is employed for the discharge between the anode and cathode in order to favor the passage of current at very low pressure. A silica anticathode is used which has the advantages of infusibility and of giving no disturbing X radiation. The two cathode slits which give direction to the beam of positive rays are of aluminium 2 mm. long and 0.05 mm. wide. The space between the slits 10 cms. long is kept at the

⁵ F. W. Aston, *Phil. Mag.* (6) 39, C11-26 (1920).

highest possible vacuum by a side tube of charcoal immersed in liquid air. Beyond the slit system is the electrical field, 200 to 500 volts, between two flat brass surfaces 2.8 mms. apart and 5 cms. long. Beyond the electrical field is the magnetic field in which the rays pass between the pole pieces of a large DuBois magnet of 2500 turns, the faces of which are circular, 8 cms. in diameter and 3 mms. apart. The current for the magnet is provided by a set of large accumulators. A current of 0.2 ampere just brings the H lines onto the plate, while 5 amperes just bring the singly charged Hg lines into view. The camera chamber is provided with a special plate holder arranged so that the plate can be shifted for several different exposures without opening the chamber. Exposures from 20 seconds for the H lines, up to 30 minutes or more are required. The discharge in the large chamber is maintained by means of a large induction coil with a Hg coal-gas break. 100 to 150 watts are passed through the primary circuit, and the bulb itself takes 0.5 to 1.0 milliampere at 20,000 to 50,000 volts.

The measurement of the photographic plates to determine the mass of the positive rays is made by means of a special comparator capable of measuring in two directions. Theoretically an unknown mass may be determined from *one* known on the same plate, but practically, greater accuracy is obtained by bracketing the unknown with several known lines just as in ordinary spectral line measurements.

The photographic method does not yield an insight into the relative quantities of the different rays. This has been accomplished by Thomson by substituting for the camera a Wilson tilting electroscope to determine the total charge under the following conditions. The condenser into which the positive rays are received is provided with a parabolic slit, which in principle might be moved to any part of the field to admit rays of a given mass for quantitative measurement by means of their charge. Instead of actually moving the slit it is made stationary and the rays of different masses are successively brought to it by varying the magnetic field strength.

Thomson has determined the various types of ions which are produced in different gases. The variety of ions for a given substance is very large compared with electrolytic ions. Certain characteristics have been pointed out by Thomson which are

very useful in determining what mass is represented by a given m/e value. Multiple charge is found only in the case of atoms.⁶ Molecules either of elements or of compounds have not been found to be multiply charged with either sign.⁶ The heavy atoms show multiple charge to a higher degree than do the lower ones. There is no apparent relation between the chemical properties of the element, such as valence and the number of charges. Mercury can have as many as eight charges, oxygen, nitrogen, and neon two; hydrogen never more than one, which is the only element examined for which no multiple charges have ever been found.

61. Isotopes of Neon.

As early as 1912 Thomson obtained some evidence by the positive ray method of the existence of particles of mass 22 in neon gas. Aston⁷ has recently determined the mass spectra of neon by the positive ray method with an accuracy of 1 in 1000 parts. The measurements show conclusively that neon consists of two isotopes of masses 20 and 22, in the proportion of about nine of the former to one of the latter, which accounts for the observed atomic weight 20.2. There is also a faint indication of a third isotope of mass 21 in a proportion estimated as less than 1%. If this third isotope proves to have real existence it will constitute a very interesting continuation of the system of triads like iron, nickel and cobalt, which was predicted in 1895 by Reynolds,⁸ purely from analogy with the three other well known groups of triads.

Attempts have been made by Lindemann and Aston⁹ to separate the two modifications of neon by fractional distillation and by fractional diffusion through pipe-clay. Later Lindemann¹⁰ discussed the theory of the separation and decided that the negative result obtained was the one to have been expected under the experimental conditions, in the case of fractional distillation. The fractional diffusion resulted in an apparent difference of density of about 0.7%, while an automatic method

⁶ Except in case of fluorides of boron and silicon. (F. W. Aston, *Phil. Mag.* (6) 40, 630 (1920).

⁷ F. W. Aston, *Phil. Mag.* (6) 39, 449-55 (1920).

⁸ E. Reynolds, *Nature*, March 21, 1895.

⁹ F. A. Lindemann and F. W. Aston, *Phil. Mag.* (6) 37, 523-35 (1919).

¹⁰ F. A. Lindemann, *ibid.*, 38, 173-81 (1919).

started in 1914 gave a difference of only 0.3%. It can therefore be said at the present time that the diffusion method in the case of neon has given positive results but the differences are too small to be conclusive.

62. Discovery of Other New Isotopes by Aston.

Still more recently Aston¹¹ has extended the search for isotopes by the positive ray method to other elements. His investigations have yielded results which, while absolutely astounding to chemists in one sense, must be regarded as having been foreshadowed by Prout's¹² hypothesis more than one hundred years ago. At the time of writing (Oct., 1920) eighteen elements have been examined by Aston with the following results, H, He, C, N, O, F, P, and As give a pure mass spectrum indicating but one isotope, as would be expected from their whole number atomic weights. The results for the other elements can be seen in the following Table XVIII. The case of bromine is of particular interest. Although its atomic weight (79.92) is quite close to 80, there appears to be no isotope of the mass 80 at all, but two isotopes in almost equal quantities of 79 and 81.

As the atomic weights of the elements increase it becomes more difficult to get a definite resolution of isotopes of masses differing by one or two units, since the percentage difference is small. The whole number rule on the basis of O = 16 has not hitherto been departed from in any case except hydrogen. This may be related to the absence of electrons in the hydrogen nucleus. At any rate it seems very well established that the departures of the ordinary atomic weights from unity is to be accounted for by a mixture of whole number isotopes. The occurrence of isotopes appears to become more common among the elements of higher atomic weight; apparently, there are more complex than simple elements. The influence this is likely to have in practical and theoretical chemistry has been expressed by Aston (*loc. cit.*) as follows. "The very large number of different molecules possible when mixed elements unite to form compounds would appear to make their theoretical chemistry

¹¹ F. W. Aston, *Nature*, 105; p. 8; p. 546; pp. 617-19 (1920). *Phil. Mag.* (6) 39, 611-25; 40, 628-34 (1920).

¹² W. Ostwald, *Grundriss d. allgemeinen Chemie* (1899), p. 41. S. L. Bigelow, "Theoretical and Physical Chemistry" (1912), p. 87.

TABLE XVIII

Isotopes¹³ of the Ordinary Elements According to Positive Ray Analysis by Aston¹⁴

<i>Element</i>	<i>Atomic Number</i>	<i>Atomic Weight</i>	<i>Minimum No. of isotopes</i>	<i>Mass in the Order of Intensity</i>
H	1	1.008	1	1.008
He	2	3.99	1	4
B	5	10.9	2	11, 10
C	6	12.00	1	12
N	7	14.01	1	14
O	8	16.00	1	16
F	9	19.00	1	19
Ne	10	20.2	2	20, 22, (21)
Si	14	28.3	2	28, 29, (30)
P	15	31.04	1	31
S	16	32.06	1	32
Cl	17	35.46	2	35, 37, (39)
A	18	39.88	(2)	40, (36)
As	33	74.96	1	75
Br	35	79.92	2	79, 81
Kr	36	82.92	6	84, 86, 82, 83, 80, 78
X	54	130.2	5	(128, 131, 130, 133, 135)
Hg	80	200.6	(6)	(197-200), 202, 204

almost hopelessly complicated, but if, as seems likely, the separation of isotopes on any reasonable scale is to all intents impossible, their practical chemistry will not be affected, while the whole number rule introduces a very desirable simplification into the theoretical aspects of mass."

The attempts of Lindemann and Aston to separate the two modifications of neon have already been referred to. A number of experiments to this end have already been carried out with other elements, and doubtless in the future we may expect much activity in the same direction. It also appears highly desirable that a series of very accurate atomic weight determinations should be made of the complex elements from different sources to

¹³ A list of the radioactive isotopes will be found in Appendix, Table B.

¹⁴ F. W. Aston, *Phil. Mag.* (6) 40, 633 (1920).

ascertain if the isotopes always occur mixed in the same proportion.

No attempt to separate isotopes has as yet been conclusively successful. In the case of radioactive and ordinary lead, Richards and Hall¹⁵ obtained wholly negative results by the use of fractional crystallization. Harkins¹⁶ and his co-workers have been engaged in the attempt to separate chlorine by diffusion and have obtained encouraging though not finally positive results. The theoretical aspects of the separation of chlorine by various methods have been the subject of much recent discussion.¹⁷

Brönsted and v. Hevesy¹⁸ report the separation of mercury into two fractions by distillation, one having a density 0.999980, the other of 1.000031, compared with that of the original as unity.

63. General Properties of Recoil Atoms.

The treatment of the chemical action produced by recoil atoms does not fall under the title either of α particles or electrons, but since the emission of α radiation and, to a much smaller degree, of β radiation is always accompanied by recoil, and since it has recently been shown that the recoil atoms are capable of producing chemical action, it appears appropriate to treat the subject briefly in the present monograph. Before proceeding to the chemical effects it will be necessary to consider the more general characteristics of recoil atoms.

When a radioactive atom emits an α particle in a given direction the parent atom, or atomic residue, receives an impulse in the opposite direction, which has very aptly been termed *recoil*. The atom receiving the recoil is termed the recoil atom. Recoil atoms were first studied by Miss Brooks,¹⁹ by Hahn,²⁰ and by Russ and Makower²¹ as a means of separating the recoiling radioactive substance in a pure state.

¹⁵ T. W. Richards and N. F. Hall, *Journ. Amer. Chem. Soc.* 39, 531-41 (1917).

¹⁶ W. D. Harkins, *Science*, 51, 289 (1920).

¹⁷ T. R. Merton and H. Hartley, *Nature*, 105, 104 (1920); W. D. Harkins, *ibid.*, 105, 230; D. L. Chapman, *ibid.*, 105, 487; 642; F. Soddy, *ibid.*, 105, 516; A. F. Core, *ibid.*, 105, 582.

¹⁸ J. N. Brönsted and G. v. Hevesy, *Nature*, 106, 144 (1920).

¹⁹ Miss H. T. Brooks, *Nature*, July 21, 1904.

²⁰ O. Hahn, *Verh. deut. phys. Ges.*, 11, 55 (1909).

²¹ S. Russ and W. Makower, *Proc. Roy. Soc.* 82A, 205 (1909).

Rutherford²² has shown that when a particle of mass m is ejected with velocity v from an atom of mass M , the residual atom of mass $M-m$ recoils with a velocity V , according to the relation $(M-m)V = mv$. In the case of Ra A of atomic weight 218 (Table I) the expulsion of the α particle of mass 4 at a velocity of 1.82×10^9 cms. sec.⁻¹ results in a recoil atom of Ra B with a velocity of 3.4×10^7 cms. sec.⁻¹. This velocity is sufficient to ionize a gas in which the recoil radiation takes place, as has been shown by Wertenstein.²³ The velocity and kinetic energy of the recoil atoms may be calculated to be about 1/50 to 1/60 that of the corresponding α particles. The fraction in each case is equal to $\frac{m}{M-m}$.²⁴

Wertenstein,²⁵ in the laboratory of Mme. Curie, has made the most exhaustive investigation of recoil atoms yet undertaken. He has called the recoil atoms from Ra A a particles. They have a range in air at atmospheric pressure of 0.14 mm., and in hydrogen of 0.83 mm. This range in air is about 1/350 that of the α particle; and since the kinetic energy of the a particle is 1/50 that of the α particle, it is evident that the expenditure of energy by the a particle is about seven times as great per length of path as that of the α particle. This does not mean that the ionization is seven times as great, because the proportion of energy expended in producing ionization is somewhat smaller in the case of a particles, but Wertenstein found that the ionization produced by α particles becomes *in maximo* about five times as great as that of a particles over the same path.

This knowledge of recoil atoms will suffice at least for a preliminary survey of what may be expected if they produce chemical action in anything like the same proportion to their ionizing powers that α particles do. The two most prominent properties to be kept in mind are their very limited range and their great intensity of action within that range. In a vessel of infinitely large volume in which the α particles would expend all their energy in the gas system without striking the wall, the comparative effect of the recoil atoms would be less than 2%, or very

²² E. E. Rutherford, "Radioactive Substances and Their Radiations" (1913), p. 174.

²³ L. Wertenstein, *Comp. rend.* 152, 1657 (1911).

²⁴ Meyer and v. Schweidler, "Radioaktivität" (1916), p. 129.

²⁵ L. Wertenstein, *Thesis*, Paris, 1913.

small. On reducing the volume or pressure, the effect of the easily absorbed recoil atoms remains constant, while the α particles expend part of their energy in the wall, which part was shown in Chapter VI to be ineffective in producing chemical action. As the volume is further diminished the α particles have still shorter paths and the effect of the recoil atoms becomes relatively greater and greater. In very small volumes and at low pressures it is evident that the ionizing and chemical effects of the recoil atoms would exceed the effect of α particles by several fold. That this is exactly the case found experimentally with respect to chemical action will be shown in the following section.

64. Chemical Reaction Produced by Recoil Atoms.

In § 43 the influence of the size of the reaction vessel on the rate and extent of the combination of hydrogen and oxygen in equivalent proportions mixed with radium emanation was demonstrated. The general law found experimentally and based in principle upon the average path of α particles in the reaction vessel is for spheres: $\log P/P_0 / E_0(e^{-\lambda t} - 1) = 84.1/D^2$, in which P_0 is the initial pressure of electrolytic gas in mm. of Hg, P the pressure of the same at any time t , E_0 is the initial quantity of radium emanation in curies, $e^{-\lambda t}$ expresses the rate of decay of emanation, and D is the diameter of the spherical reaction vessel in cms. The expression was shown to be true for spheres with diameters up to about 10 cms. containing electrolytic mixture not exceeding one atmosphere pressure. On attempting to apply the kinetic equation represented by the left hand side of the equation just given, to the case of a sphere of diameter as small as 1 cm., it was found that a velocity constant could not be obtained as in the case of larger spheres (Table XI). The experimental data of Lind²⁶ are shown in Table XIX for a sphere of about 1 cm. diameter which should have, according to the general relation for larger spheres, a value of velocity constant ($k\mu/\lambda$) of 90.4, but, as will be seen, the value of the first measurement was 104.6, which rose as the reaction progressed to a value of 220.5. If the velocity constant be calculated for each separate interval, as explained in § 45, the rise of the ($k\mu/\lambda$)' becomes still more marked, as may be seen in the table. But the time intervals

²⁶ S. C. Lind, *Journ. Amer. Chem. Soc.* 41, 533 (1919).

are still too large. To avoid this, Curve 1 in Fig. 7 was plotted with pressure as ordinates and time as abscissæ. The interpolated values of P in Table XIX were then taken from the curve from which the values of $(k\mu/\lambda)'$ in the last column were calculated. Curve 1a in Fig. 7 shows the course of the normal pressure reduction by α rays alone in larger vessels, as calculated from the general equation.

TABLE XIX

Effect of Recoil Atoms in Producing an Abnormal Rate of Combination of Hydrogen and Oxygen in a Small Sphere

Vol. = 0.470 c. c. Diam. = 0.9647 cm. $E_0 = 0.04234$ curie.
Normal $k\mu/\lambda = 90.4$.

Actual Data			Calculated from Actual Data		Interpolated Data			
Days	Hrs.	P in mm. Hg	$k\mu/\lambda$	$(k\mu/\lambda)'$	Days	Hrs.	P	$(k\mu/\lambda)'$
0	0.0	507.8	.....	.....	0	0.0	507.8	.....
					0	6.0	425.0	95.6
0	15.67	310.3	104.6	104.6	0	12.0	354.0	102.7
					0	18.0	290.0	117.1
0	19.90	271.2	105.9	111.2	1	0.0	233.0	134.4
					1	6.0	187.0	141.6
0	23.67	235.1	111.4	142.9	1	12.0	150.7	145.0
					1	18.0	123.0	148.8
1	15.33	135.4	121.4	139.0	2	0.0	96.0	182.4
					2	6.0	73.0	210.9
1	19.00	119.0	123.4	148.7	2	12.0	51.5	278.9
					2	18.0	33.0	377.6
2	5.00	76.7	134.8	195.0	3	0.0	19.5	461.7
					3	3.0	14.0	594.3
3	0.33	18.8	181.3	349.6	3	6.0	9.9	646.0
					3	9.0	7.5	528.5
3	15.42	5.0	220.5	483.3	3	12.0	5.7	535.1
					3	15.42	5.0	228.3

To ascertain whether the abnormality observed for the 1 cm. sphere could be accounted for by the action of recoil atoms added to that of α particles, the following analysis of the results was

made. If 90.4 is the normal velocity constant for α particles, 180.8 will represent a velocity where the action of recoil atoms is just equal to that of α particles under the same conditions. By plotting the $(k\mu/\lambda)'$ values from the last column of Table XIX as Curve 2 of Fig. 7, it was found that $(k\mu/\lambda)'$ becomes equal to 180.8 at a gas pressure of 118 mms. At any other pressure the proportion of chemical action being produced by each type of radiation can be estimated on the following basis:

1. That the chemical effect of the recoil atoms remains constant down to a very low pressure at which they also begin to reach the wall in large proportion without being stopped by the gas.

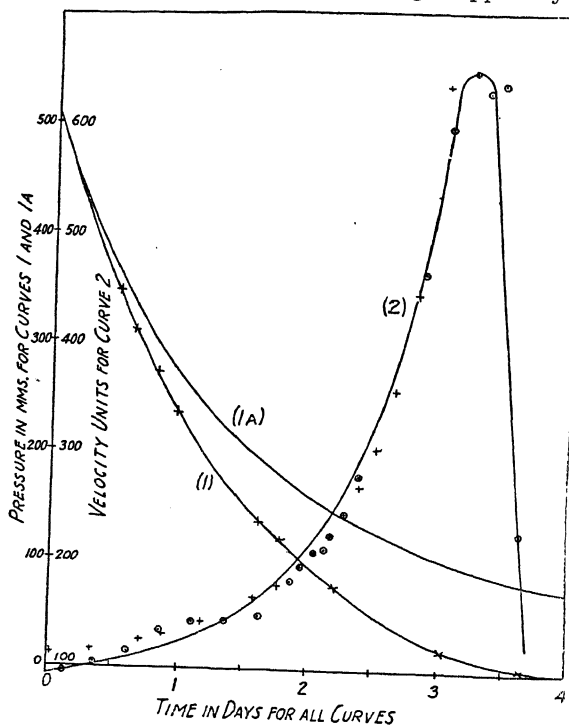


FIG. 7.

2. That the chemical effect of the α particles will at all pressures be proportional to the pressure.

For example, at 118 mms. the two effects are equal to each other and one can arbitrarily place each equal to 118. At any other pressure, 50 mms. for example, the recoil atom effect, which

for convenience will be called the R effect, would still have the value 118; the α effect now will have the value 50; the combined effect is 168; the *abnormality factor*, or the ratio of the observed abnormal effect to the normal α effect, will be $(R + \alpha)/\alpha = 168/50 = 3.36$. Table XX shows this same analysis carried to its upper and lower limits.

Comparison of the last two columns of Table XX shows that the general trend of the experimental and calculated values of the velocity constant $(k\mu/\lambda)'$ is the same. The calculated values will be found plotted in Curve 2 of Fig. 7 as +, the interpolated values taken from Table XIX as \odot . The agreement between theory and experiment is satisfactory. The maximum value found, 632, when divided by the normal α value 90.4, shows that the maximum ratio $(R + \alpha)/\alpha$ is 6.99. According to Wertenstein (*loc. cit.*) the maximum ionization due to recoil atoms from Ra A is five times that of the α particles over the same path, which would be a combined ionization six times that of the α particles alone. Remembering that Wertenstein's statement refers to recoil atoms from Ra A alone, while with emanation we are dealing with three different sets of α particles, the agreement is perhaps as good as could be expected. At least one must be convinced that recoil atoms cause the combination of hydrogen and oxygen at ordinary temperature, and approximately in the same proportion to their ionizing powers as in the case of α particles.

At first thought it must appear surprising that the chemical effect of recoil atoms can be observed at fairly large pressures. One must consider, however, that the radius of the reaction bulb is only 4.8 mms., and that the average path within the spherical bulb is only about 6/10 of this, or about 2.9 mms.; moreover, the range of the α particle in the electrolytic mixture will be about 0.3 mm. at standard pressure (calculated from Wertenstein's measurements for air and for hydrogen), and would be still greater for recoil atoms of Ra C. These facts, considered together with the intensity of the energy expense by recoil atoms, make it evident that the pressure and bulb dimensions at which the chemical effect of recoil atoms manifests itself are quite concordant with Wertenstein's ionization data.

Finally it should be inquired whether the chemical effect of recoil atoms will not also be observed in larger spheres at low

pressure. The answer must be affirmative, with certain reservations. By referring to Table XI it will be seen that for the 2-centimeter sphere there is an unmistakable tendency for $k\mu/\lambda$ to increase slightly toward the end of the reaction, which tendency would be brought out much more distinctly by calculating for $(k\mu/\lambda)'$. However, the quantity of gas to be acted on in larger spheres, beginning with normal pressure, is so much greater than in a 1-cm. one, that before low pressures are attained, the emanation is nearly exhausted and the effect on the $k\mu/\lambda$ value is largely masked.

TABLE XX

Analysis of the Recoil Atom Effect (R) and the α Ray Effect (α) in Causing Electrolytic Hydrogen and Oxygen to Combine in a 1 cm. Sphere

R effect = constant = 118. α effect proportional to pressure = P.

$\alpha = P$ (mm. Hg)	$R + \alpha$	$(R + \alpha)/\alpha$	$(k\mu/\lambda)'$ Calcd.	$(k\mu/\lambda)'$ Found (Curve 2)
10	128	(12.80)	...	...
20	138	6.90	622	632
30	148	4.93	444	446
40	158	3.95	356	376
50	168	3.36	303	350
60	178	2.97	268	292
70	188	2.69	242	267
80	198	2.48	223	240
90	208	2.31	208	223
100	218	2.18	195	204
110	228	2.07	186	192
120	238	1.98	177	182
130	248	1.91	172	166
140	258	1.84	166	162
150	268	1.79	161	153
200	318	1.59	143	133
250	368	1.47	132	118
300	418	1.39	125	112
400	518	1.29	116	100
500	618	1.24	113	95
600	718	1.19	107	...

The almost vertical drop in Curve 2, Fig. 7, after passing the maximum is due to practical exhaustion of the electrolytic gas mixture. The experimental method employed was the same as that described in § 42, and is not applicable to extremely low pressures with accuracy. It would be very interesting to examine this reaction, using a refined pressure method in order to investigate more precisely the course of the reaction near its end. Theoretically the abnormality factor should continue to rise until the gas is completely exhausted.

Chapter 12.

Atomic Disintegration by α Particles.

65. Scattering and Impacts of α Particles.

The great potency of the α particle as an agent in the production of chemical action has been frequently emphasized in preceding chapters. The reactions treated up to the present have been of ordinary molecular character. Very recently Rutherford has demonstrated conclusively for the first time that under certain conditions the α particle is capable of producing a much more fundamental chemical change, namely, the disintegration of the atom into new kinds of atoms. Although such changes are spontaneously taking place among the radioactive elements, Rutherford has presented the first evidence that can be accepted without doubt, of the artificial disintegration of the atom. These intra-atomic reactions fall very properly within the confines of radiochemistry. It will therefore be attempted to give a brief non-mathematical description of Rutherford's work which led up to and proved absolutely this discovery of preeminent importance.

The investigations of Rutherford and his co-workers in Manchester and more recently in Cambridge of the phenomena accompanying the passage of α particles through matter have been remarkably successful in furnishing insight into the question of atomic structure. As has been pointed out, the flight of the α particle of high velocity carries it in a straight line through a large number of molecules or atoms, which are ionized by the removal of a single electron from each molecule encountered. The α particle suffers no deflection in the ordinary encounter, but has its velocity gradually diminished until it is no longer able to produce ionization. Toward the end of its path, when its velocity is much reduced, the α particle is more subject to deflection or scattering, and occasionally it experiences a very large deflection or is actually turned backward in its path. The

great rarity of the occurrence of the large deflections led, as has already been pointed out, to the Rutherford-Bohr atomic model according to which most of the atomic mass is centered in an extremely minute nucleus with a positive charge equal to the atomic number of the atom, which for the heavier elements is somewhat less than half the atomic weight.

The large deflections or reversals of the α particle are then attributed to a close impact of the particle with the nucleus of the atom encountered. These impacts were first investigated using thin sheets of the heavier metals. The law governing the deflection or scattering was worked out by Geiger and Marsden,¹ on the basis of repulsion inversely with the square of the distance from point charges. The experimental scattering was in good agreement with this theory and it was calculated that the direct impact represents an approach of the α particle to the nucleus within about 3×10^{-12} cm. *in the case of heavy atoms.*

The case for light atoms is different in two important respects. First, on account of the smaller nuclear charge the repulsion of the positively charged α particle is much less than in the case of heavy atoms, and the α particle is therefore able to approach much closer to the nucleus, approximately ten times as close. This close approach on impact produces radical differences in the result of the repulsion which will be described later. Second, on account of the smaller mass of the nucleus of light atoms they are repelled to greater distances than the heavy ones. Under favorable circumstances the light atoms are projected forward at a velocity which carries them beyond the range of the impelling α particle and can be detected and counted by the scintillation method. This opens new possibilities for their investigation, which have been utilized by Rutherford as will be recounted in the following paragraphs.

Darwin² has shown that the law of scattering and repulsion predicts that all the light atoms up to and including oxygen should be capable of being repelled by a doubly charged α particle to a distance exceeding the range of the α particle in the same medium, provided that the atom repelled has a *single* positive charge. Evidently, if the repelled atom has a double charge, no atom heavier than helium could be repelled beyond

¹ H. Geiger and E. Marsden, *Phil. Mag.* (6) 25, 604 (1913).

² C. G. Darwin, *Phil. Mag.* (6) 27, 499 (1914).

the range of the α particle, without borrowing energy from some other source. It was to test this prediction that Rutherford undertook the experiments which have led to other highly significant conclusions.

66. Swift Hydrogen Atoms.

In the case of the repulsion of a hydrogen atom as the result of an intimate impact with an α particle, we have a case of great simplicity in some respects. On account of its having but a single electron it is impossible for the nucleus of the hydrogen atom to carry more than a single positive charge. On account of its elemental nature there is little probability of the hydrogen atom being changed or disrupted by impact with an α particle. On the theory of impact one should expect a hydrogen atom to be set into swift motion as the result of a direct nuclear encounter with an α particle, with a velocity 1.6 times that of the α particle. The range to be expected for the swift hydrogen atom would be about four times that of the α particle, and its kinetic energy 0.64 of the energy of the α particle. Marsden³ found that the passage of α particles through hydrogen did produce a large number of faint scintillations on a zinc sulfide screen which could be detected far beyond the range of the α particle. Rutherford⁴ has made a very detailed study of the subject which confirmed the theoretical predictions. The swift H atoms have a range in hydrogen of 100 cms., about four times that of the α particle in the same gas. The number projected straight forward by an α particle of range 7 cms. is 30 times greater than required by the simple theory of scattering. The probable explanation is the distortion of the nucleus by such close approach, which was about 3×10^{-13} cm., or approximately the same as the diameter of an electron. The direction of the swift H atoms is mainly the same as that of the α particle, and the velocity of different particles is uniform. On reducing the velocity of the α particle the direction of the H atoms becomes more varied, approaching the requirements of the law of scattering as to distribution, but still exceeding theory in number. In traversing one cm. of hydrogen about 10^5 α particles produce one swift H atom, which means

³ E. Marsden, *Phil. Mag.* (6) 27, 824 (1914). E. Marsden and W. C. Lantsberry, *ibid.*, 30, 240 (1915).

⁴ E. E. Rutherford, *Phil. Mag.* (6) 37, 537-61; 562-71 (1919).

that out of 10^9 hydrogen atoms ionized, only 1 is set into swift motion as the result of a direct nuclear impact.

Since the nuclear impact is an atomic phenomenon, the long range swift atoms can be produced by radiating either the element or any compound of it. This fact has proved a source of some embarrassment in the case of hydrogen, since it is very difficult to remove water vapor and possibly other compounds containing hydrogen from the field of action. As a consequence every source of α radiation has been found to give some swift H atoms continuously. So persistent is this phenomenon that it has suggested the possibility of the emission of H particles from the nucleus of the radioactive element itself in the same way that α particles are emitted. Later evidence obtained by Rutherford (*loc. cit.*) does not appear to support such an hypothesis strongly, but the question is still regarded by Rutherford as a subject requiring further investigation.

Both magnetic and electrostatic methods of deflection have been used by Rutherford in examining the charge and velocity of the swift H atoms. The charge was shown to be unipolar positive, and the maximum velocity is 1.6 times that of the α particle, as required by theory.

67. Experiments of Rutherford with Other Light Atoms.

After obtaining such important results with hydrogen Rutherford⁵ proceeded to investigate the propulsion of some of the other light atoms to distances beyond the range of the α particle. Assuming *singly* charged particles as the result of impact, it was predicted from Darwin's formulation that the swift nitrogen atom ought to have a range 1.33 times that of the α particle producing it, and that oxygen should similarly have the value 1.12. Both of these gases were examined by Rutherford, who found numerous scintillations beyond the α range in the region 7-9 cms. from the source, which in number corresponded closely to that found in the hydrogen experiments, indicating that the nature of the impact was similar. The range found for nitrogen was approximately that predicted by theory. In the case of oxygen the range was not very different from that found for nitrogen. This value greater than theory was rather puzzling,

⁵ E. E. Rutherford, *Phil. Mag.* (6) 37, 571-87 (1919).

but Rutherford was inclined to believe that the swift particles were in both cases the singly charged oxygen or nitrogen atoms.

The improbability of this assumption was pointed out by Fulcher,⁶ who showed that the propulsion of a singly positively charged atom of nitrogen (or oxygen) involves the assumption that the other orbital electrons are carried with the swift atom. According to Fulcher's contention the forces binding these remote electrons to the nucleus are not sufficient to overcome their initial inertia at the moment of impact, when they would have to take on a speed of 10^9 cm. sec.⁻¹ in less than 10^{-18} sec. According to Fulcher the remaining electrons would either be left behind initially or soon be brushed off by contact with other molecules of the gas traversed. The swift particles could not be nitrogen or oxygen atoms without electrons, for such multiply charged atoms would have shorter ranges than were observed. Fulcher suggests that the swift particles are α rays produced by the disruption of nitrogen by the impact. Of course doubly charged helium atoms could not be projected beyond the range of the bombarding α particle unless they got additional energy from some other source. Fulcher suggested that the impact results in the explosion of the nitrogen atom so that the internal atomic energy becomes available, just as in the case of the radioactive changes. This would represent a type of "artificial radioactivity" which will be discussed in § 69. The only difficulty of Fulcher's assumption lay in its failing to explain the uniform direction of the swift particles in the direction of the α particle. The result of an atomic explosion would be expected to cause the ejection of α particles in any direction according to the law of chance. The probability of atomic disruption by α particles had already been established for nitrogen in another way by Rutherford, which will be considered in the following section.

68. Decomposition of Nitrogen and Oxygen.

In June 1919 Rutherford⁷ reported the observation of an anomalous effect in nitrogen bombarded by α rays. A closed metal box containing an intense source of Ra C at 3 cms. from the end was provided with an opening in the end covered with a silver plate of stopping power equivalent to 6 cms. of air. The

⁶ G. S. Fulcher, *Science* 50, 582-4 (1919).

⁷ E. E. Rutherford, *Phil. Mag.* (6) 37, 581-7.

ZnS screen was placed just outside the opening at 1 mm. distance. The number of "natural" scintillations on this screen, owing to some unavoidable source of swift H atoms, is increased by exhausting the box. On admitting dry air or CO₂, the number of scintillations is diminished in the ratio to be expected from the increase of stopping power of the gas column. But if *nitrogen* is admitted the number of scintillations *increases*. Nitrogen from different sources was tried and various attempts were unsuccessful in explaining the phenomenon without assuming that H atoms were being bombarded from nitrogen atoms by α rays. The observed range of the swift particles was too great for them to have a mass greater than that of the H atom; the effect seemed to depend on the presence of nitrogen and to be proportional to its concentration, so that no other conclusion was left open except that nitrogen is disrupted by α ray bombardment and that one of the products of the disruption is the swift H atom.

Upon going to Cambridge, Rutherford^{*} continued his work on the nuclear constitution of atoms, and devised a comparison method of examining the magnetic deflection of the swift particles in order to estimate the mass. The results of the experiments confirm that the long range particles from nitrogen are particles with the same mass as the H atom, as Rutherford had previously supposed. The investigation of the shorter range particles from oxygen and nitrogen has in part confirmed the predictions of Fulcher. In both cases they appear to be doubly charged helium atoms and not the singly charged atom of nitrogen or oxygen; but instead of having the usual mass 4 of the He atom, a mass of 3 was found which according to Rutherford represents an isotope of helium. In the case of oxygen no very long range particles corresponding to those of hydrogen and nitrogen are found, and Rutherford suggests that the oxygen nucleus is composed of four helium atoms of mass 3 and one of mass 4 and two nuclear or binding electrons giving a net positive charge of 8. In the case of nitrogen we have two different modes of disruption, one giving swift doubly charged atoms of helium of mass 3, the other giving swift H atoms of mass 1. Since the number of the former exceeds the latter by five to ten fold, Rutherford assumes that the two modes of disruption are independent of each other and do not occur simultaneously from the same atom. The nuclear

^{*} T. E. Rutherford, Bakerian Lecture, *Proc. Roy. Soc.* 97A, 374-400 (1920).

structure of nitrogen proposed by Rutherford is four doubly charged helium atoms of mass 3 and two singly charged H atoms of mass 1 and three binding electrons giving a net positive charge of 7. If the H atoms have an interior position in the nucleus with reference to the He atoms, as Rutherford suggests, this might account for the greater frequency of the disruption accompanied by expulsion of a swift He atom.

69. Artificial Radioactivity.

The experimental results of Rutherford just discussed in § 68 appear to confirm Fulcher's prediction (§ 67) that the shorter range swift particles from nitrogen (and also those from oxygen) are not the singly charged N and O atoms, but are doubly charged He atoms (of mass 3). Rutherford estimates that the gain in energy of motion resulting from the impact must be at least 8%, even though the subsequent motion of the disintegrated nucleus and of the bombarding α particle be neglected. Evidently this additional energy is derived from the internal atomic energy of the disrupted atom, and we have direct proof of Fulcher's "artificial radioactivity." If the excess energy utilized by the swift particle is in reality not more than 8% of the energy of the bombarding α particle, Fulcher's difficulty of explaining the uniform direction of the swift particles can perhaps be dismissed. There is no evidence that the atomic nucleus is entirely disrupted, and Rutherford inclines to the view that only a single particle is ejected from each atom and discusses the possible isotopic modifications of atoms of lower atomic weight which remain as the result of the loss of a single atom in the two types of disruption. As yet there is experimental evidence only of the swift particles of range longer than the α particle and we have no direct evidence as to the nature of the residue.

Rutherford points out that the amount of disintegration is exceedingly small. If in the case of nitrogen only one α particle in 300,000 succeeds in getting near enough to the nucleus to liberate a swift H atom with sufficient velocity for it to be detected, the entire α radiation from a gram of radium, if wholly absorbed in nitrogen, would generate only about 5×10^{-4} mm.³ of hydrogen per year. It is quite possible however that much disintegration takes place through the liberation of particles of

slower velocity which can not be detected. It is also possible that *high velocity electrons* possess sufficient energy to bring about such a disintegration, because their close approach to the nucleus would be accompanied by an attraction instead of a repulsion. In this case we should expect to find the effect possibly more pronounced in the case of the atoms of high atomic number than of lower. It is possible that some of the inert gases found by various authorities by spectral methods may have resulted from intense electronic bombardment of the electrodes. The results of further experiments in this direction may be awaited with a great deal of interest. Rutherford does not consider it impossible that penetrating X rays may have sufficient energy to cause atomic disintegration.

It may not be without interest to observe that the discovery of radioactivity came about as the result of the search for the spontaneous emission of X rays. We now have the situation reversed; having discovered radioactivity and the spontaneous disintegration of the atom, we turn back to its artificial disruption, and enter upon an era of renewed activity in the quest of "transmutation."

APPENDIX

Table A. Decay of Radium Examination According to L. Kolowrat

Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00	Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00	Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00
Days	Hrs.			Days	Hrs.			Days	Hrs.		
	0	1.00000		1	11	0.76913		4	3	0.47592	353
	0.5	0.99625	375	1	12	0.76338	575	4	6	0.46533	345
	1	0.99253	372	1	13	0.75768	570	4	9	0.45498	337
	2	0.98511	742	1	14	0.75201	567	4	12	0.44486	330
	3	0.97775	736	1	15	0.74639	562	4	15	0.43496	323
	4	0.97045	730	1	16	0.74082	557	4	18	0.42528	315
	5	0.96319	726	1	17	0.73528	554	4	21	0.41582	308
	6	0.95600	719	1	18	0.72979	549	5	0	0.40657	3004
	7	0.94885	715	1	19	0.72434	545	5	4	0.39455	2915
	8	0.94176	709	1	20	0.71892	542	5	8	0.38289	2829
	9	0.93473	703	1	21	0.71355	537	5	12	0.37153	2745
	10	0.92774	699	1	22	0.70822	533	5	16	0.36059	2664
	11	0.92081	693	1	23	0.70293	529	5	20	0.34994	2585
	12	0.91393	688	2	0	0.69768	525	6	0	0.33960	2509
	13	0.90710	683	2	1	0.69246	522	6	4	0.32956	2435
	14	0.90032	678	2	2	0.68729	517	6	8	0.31982	2363
	15	0.89360	672	2	3	0.68215	514	6	12	0.31037	2293
	16	0.88692	668	2	4	0.67706	509	6	16	0.30019	2225
	17	0.88029	663	2	6	0.66698	504	6	20	0.29229	2160
	18	0.87372	657	2	8	0.65705	496	7	0	0.28365	2096
	19	0.86719	653	2	10	0.64726	489	7	4	0.27527	2034
	20	0.86071	648	2	12	0.63763	482	7	8	0.26714	1974
	21	0.85428	643	2	14	0.62813	475	7	12	0.25924	1915
	22	0.84789	639	2	16	0.61878	468	7	16	0.25158	1859
	23	0.84156	633	2	18	0.60957	461	7	20	0.24414	1804
1	0	0.83527	629	2	20	0.60050	454	8	0	0.23693	1751
1	1	0.82903	624	2	22	0.59156	447	8	4	0.22993	1699
1	2	0.82283	620	3	0	0.58275	440	8	8	0.22313	1649
1	3	0.81669	614	3	3	0.56978	432	8	12	0.21654	1600
1	4	0.81058	611	3	6	0.55711	422	8	16	0.21014	1553
1	5	0.80453	605	3	9	0.54471	413	8	20	0.20393	1507
1	6	0.79852	601	3	12	0.53259	404	9	0	0.19790	1462
1	7	0.79255	597	3	15	0.52074	395	9	4	0.19205	1419
1	8	0.78663	592	3	18	0.50916	386	9	8	0.18637	1377
1	9	0.78075	588	3	21	0.49783	378	9	12	0.18087	1326
1	10	0.77492	583	4	0	0.48675	369	9	18	0.17291	1268
			579				361				

APPENDIX

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APPENDIX—(Continued)

Table A. Decay of Radium Examination According to L. Kolowrat

Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00	Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00	Time		Quantity Remaining $e^{-\lambda t}$	Δ 0.00
Days	Hrs.			Days	Hrs.			Days	Hrs.		
10	0	0.16530	1212	14	16	0.07136	0519	21	12	0.02086	01496
10	6	0.15803	1159	15	0	0.06721	0489	22	0	0.01906	01367
10	12	0.15107	1108	15	8	0.06329	0461	22	12	0.01742	01250
10	18	0.14442	1059	15	16	0.05961	0434	23	0	0.01592	01142
11	0	0.13807	1013	16	0	0.05613	0409	23	12	0.01455	01044
11	6	0.13199	0968	16	8	0.05287	0385	24	0	0.01330	00954
11	12	0.12619	0925	16	16	0.04979	0362	24	12	0.01216	00872
11	18	0.12063	0885	17	0	0.04689	0341	25	0	0.01111	00797
12	0	0.11533	0846	17	8	0.04416	0321	25	12	0.01015	00728
12	6	0.11025	0809	17	16	0.04159	0303	26	0	0.00928	00637
12	12	0.10540	0773	18	0	0.03916	02809	27	0	0.00775	00532
12	18	0.10076	0739	18	12	0.03579	02567	28	0	0.00647	00444
13	0	0.09633	0701	19	0	0.03271	02346	29	0	0.00541	00371
13	8	0.09072	0660	19	12	0.02990	02144	30	0	0.00452	.....
13	16	0.08543	0622	20	0	0.02732	01960	40	0	0.000747	.....
14	0	0.08046	0586	20	12	0.02497	01791	50	0	0.000123	.....
14	8	0.07577	0552	21	0	0.02282	01637	∞		0.00000	.....

List of Radioactive Isotopes, by Groups ¹⁰

α and β indicate the type of radiation. The atomic number for each group is indicated in $\left\{ \right\}$.

¹⁹ A list of the isotopes of the ordinary elements, hitherto discovered, will be found in Table XVIII, § 62.

* A list of the isotopes of the ordinary elements, hitherto discovered, will be found in Table XVIII, § 62.

¹⁰ K. Fajans, *Phys. Zeit.* **16**, 464 (1915).

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